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THE APPLICATION OF GIS (GEOGRAPHIC INFORMATION SYSTEMS) IN DIGITAL LIBRARY MANAGEMENT AND SERVICES

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ABSTRACT

The era of global technology, the tremendous growth in literature available in both digital and print formats, has provided an all-encompassing platform for research on a global scale. The implementation and utilization of GIS (Geographic Information Systems) within libraries and digital information centers have emerged as a significant area of research. This research paper highlights the practical definition and fundamental architecture of GIS. The author has conducted a comprehensive review of existing literature regarding the various fields of application for GIS within libraries in the current context. The paper explores how GIS technology enables libraries to effectively process, systematically store, and analyze available geographic data, and how this precise data facilitates the provision of enhanced library information services to library members. Furthermore, the challenges associated with the implementation of GIS have also been duly addressed. The advent of GIS technology, driven by the rapid expansion of information, introduces a new dimension that makes its effective application within libraries not only feasible but also highly appropriate, thereby ensuring the efficient and rapid delivery of information.

KEYWORDS

GIS (Geographic Information System), Geospatial Data, Library Services, Collection Management, Library Management

INTRODUCTION

The GIS system is a great medium of all-in-one technology. Using this system, information about a particular place is provided efficiently and quickly. By integrating the information, accurate understanding of the current situation, adjustment, current status is shown. Due to this, GIS technology is widely used for survey planning of future geographical problems, weather, natural calamities. "A map speaks more than a thousand words." Pictures and maps are more effective and powerful communication tools than text and charts (Chudasama, P. & Shastri, Devashree 2013). The use of GIS technology and various digital software in the library department should be open to all. This research



article discusses the role of GIS in the library department, how it can be suitable for the professional user. Library is considered as a great source of knowledge and using the latest system in the library department will help the research students to reach their conclusions.

OBJECTIVES

1. To explain and analyze the basic concepts of GIS technology.
2. To review the GIS system in the library department and explain its future availability.
3. To identify the technical challenges associated with the application of GIS for library professionals.
4. To develop a library department approach to GIS system.

OBJECTIVES

Definition and basic infrastructure of GIS:

Globally In the early 1960s, the term 'Geographic Information System' was coined by Tomlinson, who was the head of the Canadian Geographic Information System Institute. The development of GIS is based on the satellite-based Global Positioning System (GPS). GPS uses radio signals from satellites to determine precise geographic location and time, determining a location in real time or in post-processing mode. GIS technology has emerged from global geospatial weather, ecosystem geography, remote sensing, mapping, space technology, digital spatial, computer-aided design (CAD), surveying, and photogrammetry. The main terms associated with GIS are spatial data, geographic coordinates data. (point system of a location, line term, area record) Coordinating features of significant geographic location and structure are the main functions of GIS. Collecting information related to a specific geographic feature. According to Duker (1979), GIS is a special type of information systems where the database contains observations based on spatially distributed features, activities or events, which can be defined in space as leaps, lines or areas. GIS data about points, lines and areas are represented by precise lines and latitudes, making it easy to get precise information about the location on the earth's surface. It benefits research students as well as geospatial information seekers. GIS software is a system that is very easy to use. The main function of this system is to collect, store, list, locate and visualize data. These systems can mainly help library professionals manage location details of library documents, users and suppliers.



Figure 1: OPENSOURCE GIS

Areas of Application of GIS in Libraries and Information Centres:

1. Collection Management of Library Documents:

According to Dr. S. R. Ranganathan's fifth law of library and information science, library is a growing institution i.e. updated new books, reading materials are added to the library every year to enrich the library collection. By implementing a subject-wise classification scheme in the library, many resources on the same subject are brought together in one place (on the shelf). This design can make finding a particular book from the shelf a time-consuming process for users. With the help of GIS software, information can be obtained by determining the location and location of various floor maps of the library building.

2. Studying library users based on local data (especially in the context of public libraries) and mapping book distributors/suppliers:

GIS systems can be successfully implemented in libraries. Network positioning can be useful depending on the location of library users, as this system allows the local library to predict the readership and balance the demand and supply of books accordingly.

3. To design a library building:

With the help of GIS, the library building can be studied according to the equipment, width, weather, wind speed, direction of light. Information on resource sources, furniture, various attractive, cupboard design information can be studied at different places of the library.

It can be helpful to decide on redesigning library reading room, current paper reading room, as well as increasing or decreasing library furniture. Pournaghi, R. (2015) studied space use by library users in the



Central Library of Tehran University through ArcGIS software. Analyzed the data and displayed floor maps of the library which would help in space utilization assessment.

4. Management of Map Collection:

Geographical map collections are useful to support location determination education. They are also particularly needed to provide guidance in areas of study such as archaeology, history, geography, environmental resources. GIS technology has the ability to manipulate data by geographic location. Archiving of ancient, rare and important maps can be done in digital format through GIS technology. Librarians can provide reference services with the help of GIS.

5. Use of GIS in Bibliometrics:

The term bibliometrics was coined by Sir Alan Pritchard 1969. Bibliometrics is the application of statistical methods to books and literature. With the rise of ICT and the ubiquity of the Internet, there has been an increase in research and research on bibliometrics has begun along with GIS. Using this system it is possible to improve numerical knowledge.

6. Provision of advance knowledge to library readers through Geographic Information System:

The readership in a library department comes from many strata and each has different demands. The use of this system in the library department helps in gaining knowledge of the geographical situation. It helps the reader to get the information about the situation of Sabhotal quickly. Information about weather, rain, valleys, mountains, cyclones can be obtained in a few moments.

TECHNICAL CHALLENGES GEOGRAPHIC INFORMATION SYSTEM IN LIBRARIES:

Geographic Information System technology is a software based. This requires huge investment to acquire hardware, remote sensing experts and data operators, skilled users. Computers, systems, screens, desktop are all necessary equipment in the library department. Resources for collecting geospatial information are essential in libraries for information needs. Since GIS systems emphasize accuracy, location accuracy is essential. Long-term financial and technical support is mandatory for GIS implementation. This system requires the skills of GIS experts because the location data needs to be interpreted and analyzed, measured and processed.

CONCLUSION

Geographic Information System technology has provided a new direction to initiate data services in library departments. Globally various libraries are seen using this system as a digital media format. Due to this, geographic data exchange and provision of services has become faster, so there is scope for



implementing effective solutions. The main benefits of the technology are experienced in the areas of library collection management, visualization of map collections, management of library space and user studies. This article mentions the challenges for library professionals related to GIS and reviews the literature on important application areas of GIS in the library context, which is helpful in providing innovative and efficient library services.

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E-COMMERCE: A BUSINESS REVIEW FROM INDIAN CONTEXT

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ABSTRACT

This paper deals the conceptual knowledge of search engine marketing or e-commerce, literature review, current and future aspects of e-commerce in Indian context. This paper discussed about the top motivator factors of shopping online. The present development would be a valuable addition to researcher and academicians; and useful theory for practitioners, advertisers, and entrepreneurs.

KEYWORDS

SEM, Online Marketing, E-commerce, Pay-per-click (PPC)

INTRODUCTION

The rapid growth of e-commerce in India is being driven by greater customer choice and improved convenience. Having a strong business model coupled with a first-class level of service is critical to success. Before these aspects are explored, it is important to understand the unique attributes which define e-commerce in India. Khan and Mahapatra (2009) remarked that technology plays a vital role in improving the quality of services provided by the business units. One of the technologies which really brought information revolution in the society is Internet Technology and is rightly regarded as the third wave of revolution after agricultural and industrial revolution. The cutting edge for business today is e-Commerce. The effects of e-commerce are already appearing in all areas of business, from customer service to new product design. It facilitates new types of information based business processes for reaching and interacting with customers like online advertising and marketing, online order taking and online customer service etc. It can also reduce cost in managing orders and interacting with a wide range of suppliers and trading partners, areas that typically add significant overheads to the cost of products and services. Businesses are increasingly using the Internet for commercial activities. The ubiquitous nature of the Internet and its wide global access has made it an extremely effective mode of communication between businesses and customers [Rowley (2001)].



Devendraet. al., (2012) defined that electronic commerce, commonly known as e-commerce or e-Commerce, consists of the buying and selling of products or services over electronic system such as internet and other computer network. Intent is the technology for e-commerce as it offers easier ways to access companies and individuals at very low cost in order to carry out day-to-day business transactions. Search engine marketing (SEM) is a form of web advertising that companies use to promote their products and services on search engine results pages (SERPs). SEM is focused on the effective use of search engine advertisements (a.k.a., sponsored results, sponsored links) that appear on the SERP. SEM which allows firms to target consumers by placing ads on search engines has proven to be an effective audience acquisition strategy. Unlike traditional online advertising, advertisers pay only when users actually click on an ad when successfully implemented, SEM can generate steady traffic levels and tremendous return on investment (ROI).

RESEARCH METHODOLOGY

The research is mainly based on secondary data. For the purpose books, study material of educational courses and research journal, articles as well as websites and some extent primary observations of researchers have were implemented

OBJECTIVES

1. To study the major search engines in the market.
2. To study the types of e-commerce.
3. To study the trends in e-commerce.

TYPES OF E-COMMERCE

The following types of e-commerce:

- (i) B2B E-Commerce: Companies doing business with each other such as manufacturers selling to distributors and wholesalers selling to retailers. Pricing is based on quantity of order and is often negotiable.
- (ii) B2C E-Commerce: Businesses selling to the general public typically through catalogs utilizing shopping cart software. By dollar volume, B2B takes the prize, however B2C is really what the average Joe has in mind with regards to ecommerce as a whole.
- (iii) C2C E-Commerce: There are many sites offering free classifieds, auctions, and forums where individuals can buy and sell thanks to online payment systems like PayPal where people can send and



receive money online with ease. eBay's auction service is a great example of where customer-to customer transactions take place every day.

(iv) Others: G2G (Government-to-Government), G2E (Government-to-Employee), G2B (Government-to-Business), B2G (Business-to-Government).

Types of E-Commerce

The rapid growth of e-commerce in India is being driven by greater customer choice and improved convenience. Having a strong business model coupled with a first class level of service is critical to success. Before these aspects are explored, it is important to understand the unique attributes which define e-commerce in India. Amrish Rau, General Manager of First Data India and ICICI Merchant Services, discusses. India has an internet user base of over 50 million users. The penetration of e-commerce is low compared to markets like the US and the UK but is growing at a much faster rate with a large number of new entrants.

The industry consensus is that growth is at an inflection point with key drivers being:

1. Increasing broadband Internet (growing at 35% MoM) and 3G penetration
2. Rising standards of living and a burgeoning, upwardly mobile middle class with high disposable incomes
3. Availability of a much wider product range (including online purchase from international retailers and direct imports) compared to what is available at brick and mortar retailers
4. Busy lifestyles, urban traffic congestion and lack of time for offline shopping
5. Lower prices compared to brick and mortar retail driven by disintermediation and reduced inventory and real estate costs

CHARACTERISTICS OF INDIA

Some of the characteristics that define e-commerce in India are: Cash on Delivery as a preferred payment method. India has a vibrant cash economy as a result of which 80% of Indian e-commerce tends to be Cash on Delivery (COD) Direct imports constitute a large component of online sales. Demand for international consumer products (including online purchases from international retailers) is growing much faster than in-country supply from authorized distributors. E-commerce uses sophisticated technology and logistics to create a cross-border supply chain that allows consumers to shop online for international products that are delivered duty paid to their doorstep.

THE ADVANTAGES AND DISADVANTAGES OF INTERNET MARKETING



Melody and Robert (2001) remarked that the Internet can provide timely information to customers because of its ability for instant communication, and its availability 24 hours a day, 7 days a week [Lane, 1996]. On-line marketing offers more choices and flexibility [Lamoureux, 1997] and, at the same time, eliminates huge inventories, storage costs, utilities, space rental, etc., [Avery, 1997]. People tend to associate Internet marketing with direct marketing because companies participating in online marketing usually shortened the supply chain [Edwards, et al., 1998] and reduced commission and operating costs. The ability to serve as both a transaction medium and a physical distribution medium for certain goods is a unique feature of Internet marketing. Such advantages can be best realized by companies that provide digital products/services such as software, music, news, consulting services, online ticketing and reservations, telemedicine, insurance, banking, stock brokerage, tax, and other financial service industries. Using the Internet as the distribution channel can reduce not only the delivery cost substantially, but also ensures instant delivery of products/services.

Moreover, Ruckman (2012) suggested that Internet research becomes an increasingly important tool during the purchasing process; more marketers are seeing the advantages too. It's a win-win situation. Marketing departments are investing more into online marketing today because it's:

1. Attractive to a significant segment of the demographics for most customer profiles. It can effectively reach the target customer.
2. Faster and less expensive to conduct direct marketing campaigns
3. Measurable, which means that successes are identifiable and repeatable
4. Open 24-hours a day
5. Cost-effective, in the long run.

DISADVANTAGES:

There is no actual face-to-face contact involved in the Internet communication. For the types of products that rely heavily on building personal relationship between buyers and sellers such as the selling of life insurance, and the type of products that requires physical examination, Internet marketing maybe less appropriate. While internet marketing cannot allow prospective buyers to touch, or smell or taste or 'try on' the products, However a survey of consumers of cosmetics products shows that email marketing can be used to interest a consumer to visit a store to try a product or to speak with sales representatives [Martin et al (2003)]. Some of the disadvantages of e-Marketing are dependability on technology, Security, privacy issues, Maintenance costs due to a constantly evolving environment,

Higher transparency of pricing and increased price competition, and worldwide competition through globalization.

TOP MOTIVATORS FOR SHOPPING ONLINE

Top motivators for shopping online which include cash back guarantee, cash on delivery, fast delivery, substantial discounts compared to retail, and access to branded products, while barriers include inability to touch and try products before purchase, fear of faulty products, apprehension of posting personal and financial details online and inability to bargain



E-COMMERCE MARKET WOULD CONTINUE ITS GROWTH STORY

The changing consumer lifestyles, supported by the younger population base of India, have given a boost to the e-commerce business. More than half of the total 1.2 billion population of India falls under the 'below 25 years of age' bracket. Also, 65.0 per cent of India's population, representing the working age group of 15 to 64 years, would aid the further growth of e-commerce, driven by their rising disposable income. Notably, discretionary spending in India is expected to jump to 70.0 per cent by 2025 from 52.0 per cent in 2005. Also, the growing inclination towards purchasing online is reflected in a trend for higher value online transactions. Shoppers are ready to shop for values exceeding USD 500., which earlier hovered in the range of USD 40.0–100.0.

MARKET SIZE & GROWTH:



India's e-commerce market is worth about Rs 50,000 crores in 2011. About 80% of this is travel related (airline tickets, railway tickets, hotel bookings, online mobile recharge etc.). Online retailing comprises about 15%. India has close to 10 million online shoppers and is growing at an estimated 40-45% CAGR vis-à-vis a global growth rate of 8-10%. Electronics and apparel are the biggest categories in terms of sales.

MAJOR SEARCH ENGINES IN THE MARKET

By distinct search engines, means that search engines, portals, and websites who have alliances and who solicit bids for paid placements from a single source are treated as one search engine. For instance, by successfully bidding for a paid link with Overture exposes a seller to traffic from several websites, including MSN, Yahoo!, AltaVista, Info Space, Allthe Web and NetZero. There are various search engines by content/topic such as Baidu (Chinese, Japanese), Bing, Blekko, Google, Sogou (Chinese), Soso.com (Chinese), Volunia, WireDoo, Yahoo!, Yandex (Russian), Yebol, and Yodao (Chinese). Among PPC providers, Google AdWords, Yahoo! Search Marketing, and Microsoft adCenter are the three largest network operators, and all three operate under a bid-based model.

CONCLUSION

The conceptual knowledge of search engine marketing or e-commerce, literature review, current and future aspects of e-commerce in Indian context. This paper discussed about the top motivator factors of shopping online. The present development would be a valuable addition to researcher and academicians; and useful theory for practitioners, advertisers, and entrepreneurs. Some of the disadvantages of e-Marketing are dependability on technology, Security, privacy issues, Maintenance costs due to a constantly evolving environment, Higher transparency of pricing and increased price competition, and worldwide competition through globalization. While considering the aforesaid limitations; advertisers and end-users can effectively use this modern platform to make life easier and faster. In the next 3 to 5 years, India will have 30 to 70 million Internet users which will equal, if not surpass, many of the developed countries. Internet economy will then become more meaningful in India. With the rapid expansion of internet, Ecommerce, is set to play a very important role in the 21st century, the new opportunities that will be thrown open, will be accessible to both large corporations and small companies [Waghmare (2012)]. Karoor (2012) explained that Ecommerce encapsulates many of the dynamics of 21st century of India. The potential huge and wit and energy of the entrepreneurs in the sector is impressive. Online commerce in India is destined to grow both in revenue



and geographic reach. The further research areas in ecommerce are; the quality of sponsored ad text, ad position, Search Engine Optimization (SEO), PageRank, yellow pages, and bid management etc.

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GREEN DERMATOLOGY- DEVELOPMENT OF A TEA TREE OIL INFUSED ANTI-ACNE GEL

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ABSTRACT

Acne vulgaris is a common chronic inflammatory skin disorder affecting a large proportion of the global population, particularly adolescents. It is primarily caused by excessive sebum production, follicular hyperkeratinization, microbial colonization, and inflammation. Conventional anti-acne therapies, though effective, are often associated with side effects such as skin irritation, dryness, and development of antibiotic resistance. Hence, there is an increasing demand for safer and more effective herbal alternatives. The present study focuses on the formulation and evaluation of a herbal anti-acne gel based on the concept of green dermatology, incorporating tea tree oil as the primary active ingredient. Tea tree oil is well known for its potent antimicrobial and anti-inflammatory properties, making it effective against acne-causing microorganisms. Liquorice extract was included for its anti-inflammatory, antioxidant, and skin-soothing effects, while guar gum was used as a natural gelling agent to provide suitable consistency and stability to the formulation. A total of five formulations (F1–F5) were prepared by varying the concentration of tea tree oil and evaluated for various physicochemical parameters such as appearance, pH, viscosity, spreadability, homogeneity, washability, stability, and skin irritation. The pH of all formulations was found to be within the acceptable skin-friendly range (5.8–6.5), indicating suitability for topical application. All formulations exhibited good homogeneity, smooth texture, and satisfactory spreadability. The viscosity was appropriate for easy application and retention on the skin. Stability studies confirmed that the formulations remained stable under different storage conditions. Furthermore, no signs of irritation or adverse reactions were observed during the skin irritation test, indicating safety of the formulation. Among all the batches, formulation F5 showed optimum results in terms of viscosity, spreadability, pH, and overall stability, and was considered as the optimized formulation. The results suggest that the

developed herbal anti-acne gel is effective, safe, and suitable for topical use. This study supports the potential of plant-based formulations as an alternative to conventional synthetic anti-acne treatments, promoting the concept of eco-friendly and sustainable skincare.

KEYWORDS

Acne, Pores, Anti acne gel

INTRODUCTION

Acne vulgaris is a skin disease that affects 80% of the teenage population; however, it can reach 100% because it is believed that there is no one who has not had a more or less severe episode of acne throughout their life. Although acne is not a life-threatening disease, it can have serious psychosocial consequences leading to low self-esteem, social isolation, and depression, as the severe disease can leave disfiguring scars on the face and is not limited to a few papules.[1][2].

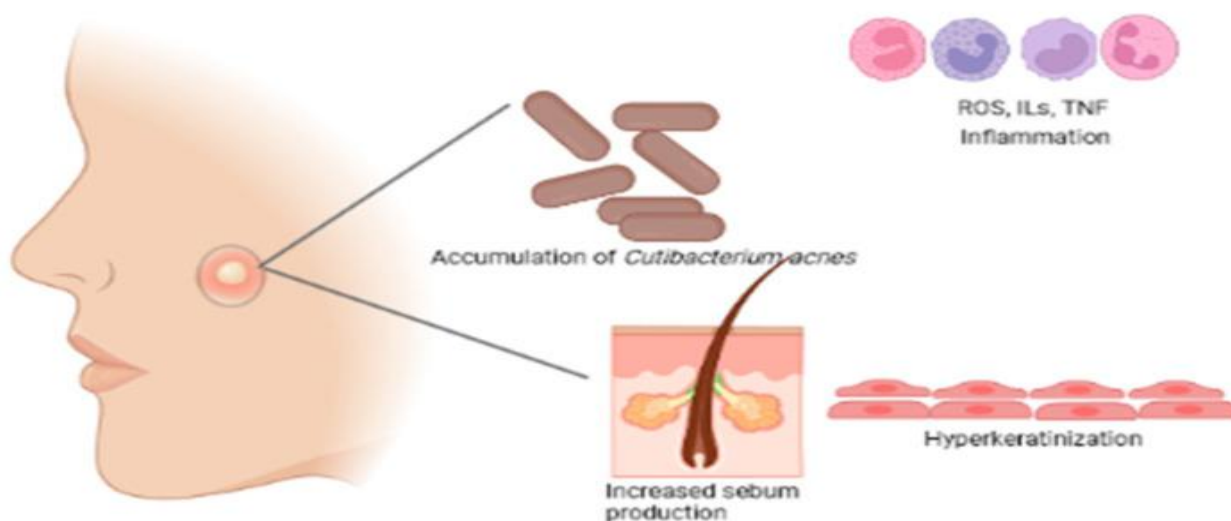


Fig 1. Acne inflammation

Acne is viewed as a chronic inflammatory skin disorder caused by a combination of factors, including excessive sebum production, abnormal desquamation of the follicular epithelium, inflammation and the presence of the bacterium *Propionibacterium acnes*. Pimples may happen when the sebaceous organs associated with pores liable for moving dead cells to the surface space of the skin get hindered. This blockade usually results in bacterial colonization and attack on the sebum, resulting in whiteheads, blackheads, and finally, inflammation and scars when the body's mechanism tries to fight back. *Propionibacterium acnes* and *Staphylococcus epidermidis* assume significant parts concerning inflammatory acne and shallow disease by utilizing sebaceous fatty substances into unsaturated fats, to which neutrophils are pulled in [3,4]. Despite their effectiveness, synthetic therapies include

drawbacks such skin irritation, peeling, and the development of resistance. Herbal alternatives with fewer side effects are being investigated as a result of the growing desire for natural therapies. Because herbal gels are they are very advantageous. The purpose of this research is to create and assess an herbal anti-acne gel that contains extracts with shown medicinal benefits [5,6]. For ages, ancient medical systems like Ayurveda, Siddha, and Unani have employed herbal therapies to treat acne and other skin-related issues. Ingredients derived from plants frequently offer a variety of functions, including antimicrobial, anti-inflammatory, antioxidant, wound-healing, and calming qualities. Herbal formulations are often well-tolerated and linked to fewer negative effects than synthetic medications. Herbal-based gels for acne treatment are becoming more and more popular as the world moves towards sustainable and natural skincare products [7,8]. It is very advantageous to use an herbal gel as a topical delivery mechanism for anti-acne chemicals. Gels enable rapid absorption, localized action, and extended contact with the afflicted region in a non-greasy, clear, and spreadable composition. They are therefore perfect for oily, sensitive skin that is prone to acne non-greasy, simple to use, and enable the gradual release of active components[9].

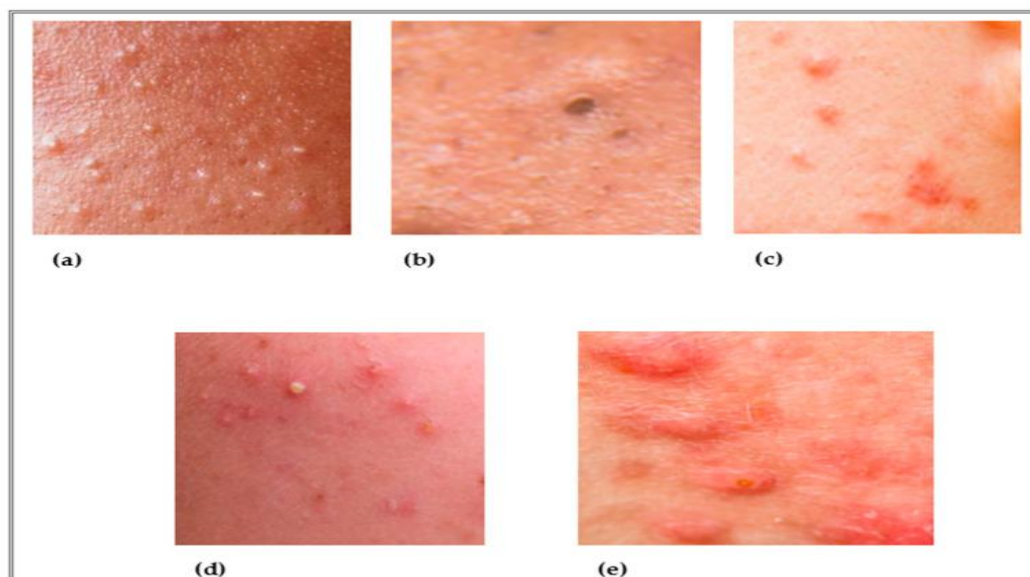


Fig 2. Types of Acne

Topical formulations such as gels are widely used for acne treatment because they provide better drug penetration, ease of application, and improved patient compliance. Herbal and plant-based ingredients are increasingly preferred in dermatological preparations due to their therapeutic efficacy and reduced side effects compared to synthetic drugs. Tea tree oil, obtained from *Melaleuca alternifolia*, is well known for its strong antimicrobial and anti-inflammatory properties. It is effective against acne-

causing bacteria and helps reduce skin inflammation and redness. Liquorice extract (*Glycyrrhiza glabra*) possesses antioxidant, anti-inflammatory, and skin-soothing properties. It also helps reduce hyperpigmentation and irritation associated with acne lesions. Carbol (phenol) has antiseptic and antimicrobial activity, which helps prevent bacterial growth and maintain skin hygiene. The combination of these active ingredients in a gel formulation can provide synergistic effects in controlling acne by reducing bacterial growth, inflammation, and skin irritation. Therefore, the present study focuses on the formulation and evaluation of a herbal anti-acne gel containing tea tree oil, carbol, and liquorice extract to enhance therapeutic effectiveness and improve skin health.

Use of Tea Tree Oil in Anti-Acne Gel

Tea Tree Oil obtained from *Melaleuca alternifolia* is widely used in dermatological and cosmetic formulations due to its strong antimicrobial and anti-inflammatory properties. It is considered an effective natural ingredient for the treatment of acne and other skin infections.

Tea Tree Oil exhibits significant antibacterial activity against acne-causing bacteria such as *Cutibacterium acnes* (formerly *Propionibacterium acnes*). By inhibiting the growth of these microorganisms, it helps prevent the formation and spread of acne lesions. In addition, Tea Tree Oil possesses anti-inflammatory properties that help reduce redness, swelling, and irritation associated with acne.

Another important function of Tea Tree Oil in anti-acne gel formulations is its ability to control excess sebum production. Excess oil on the skin can clog pores and promote acne development; therefore, Tea Tree Oil helps maintain skin balance and keep pores clear. It also has mild antiseptic and healing properties, which support faster recovery of damaged skin and reduce the risk of secondary infections. Due to these beneficial properties, Tea Tree Oil is commonly incorporated into topical formulations such as gels, creams, and lotions for acne management. In anti-acne gel formulations, Tea Tree Oil not only enhances antibacterial activity but also improves skin soothing and overall therapeutic effectiveness.

Key Functions in Anti-Acne Gel:

- Antibacterial action against acne-causing bacteria
- Anti-inflammatory effect that reduces redness and swelling
- Helps control excess sebum (oil) production
- Unclogs pores and prevents acne formation

- Promotes faster healing of acne lesions

Causative factors and pathogenesis of acne vulgaris

Several causal factors are believed to play a key part in the traditional aetiology of [acne vulgaris](#). As discussed previously, chronic acne [skin diseases](#) are caused by increased [sebum excretion rates](#), endocrinological factors such as androgens, aberrant [keratinization](#) of the follicular [infundibulum](#), bacterial infection proliferation, and consequent inflammation.

a) **Increase in Sebum production:** An increase in sebum production in the [hair follicles](#) is one of the most significant causes of acne formation. According to Gollnick et al. androgen hormones, specifically testosterone and Insulin Growth hormone (IGH-1), increase sebum synthesis and secretion [10].

b) **Hyperkeratinization abnormalities of the pilosebaceous follicles:** Generally, the healthy follicles often shed single-cell [keratinocytes](#) into the lumen, which are then ultimately eliminated. However, in acne patients, keratinocytes hyper proliferate and are not shed into the lumen, which leads to the accumulation of irregular desquamated corneocytes in the pilosebaceous follicles coupled with lipids and monofilaments.

c) **Hyper proliferation of propionibacterium acnes (*P. acnes*):** [Propionibacterium](#), which plays a substantial part in the [pathophysiology](#) of inflammatory acne, is an additional acne-causing agent. Cutibacterium acnes, formerly known as propionibacterium acnes, is an anaerobic, lipophilic, gram-positive [pathogen](#) that prefers to colonise in sebaceous follicles because they produce large amounts of sebum and provide excellent anaerobic habitat for bacterial growth.

ACNE FORMATION

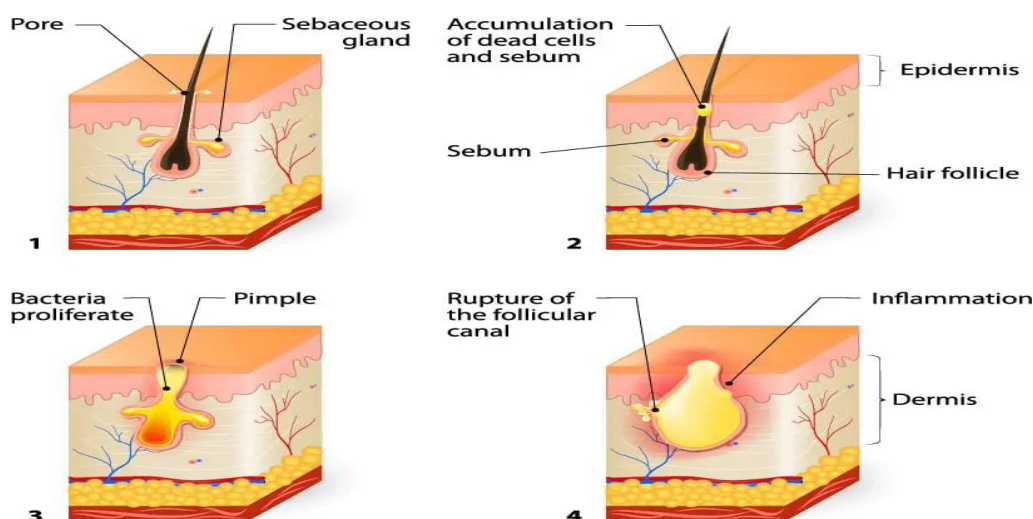


Fig 3. Acne formation

Types of acne lesions

Acne is classified into several forms, including acne conglobate, [acne rosacea](#), [acne fulminans](#), acne cosmetica, acne excoriee (picker's acne), acne medicamentosa, acne [chloracne](#), and acne mechanica. Nonetheless, acne vulgaris is the most prevalent form of acne, accounting for 99% of all acne cases. It is differentiated by two types of lesions: non-inflammatory, open and closed [comedones](#), as well as inflammatory papules, [pustules](#), nodules, and cysts[FIG4]. The comedones are of two types: a comedo that is closed is a whitehead, while another that is open is a blackhead type.[10]

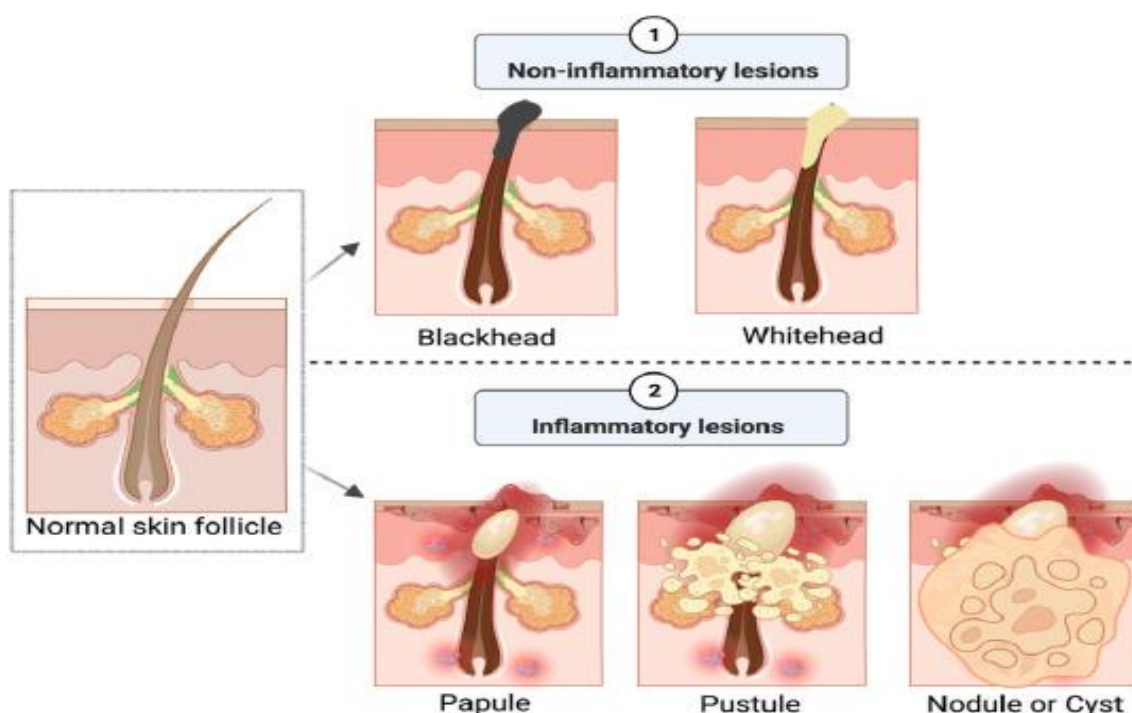


Fig. 4. Schematic illustration of major distinguishing of the two types of lesions (non-inflammatory, inflammatory) and their pathogenies.

Blackheads: Blackheads are non-inflammatory acne lesions that develop on the skin due to excess oil and dead skin cells obstructing hair shafts. A blackhead is referred to as an open comedo because the skin surface remains exposed and has a dark look, such as black or brown. Blackheads are mild acne that usually appears on the face, arms, chest, neck, back and shoulders.

Whiteheads: Whiteheads are small bumps and non-inflammatory acne lesion that develops on the skin when oil, bacteria and skin cells block the opening of hair follicle pores. Whiteheads are referred to as closed comedones since the bumps are closed and white. Whiteheads can develop anywhere on the body, but they are most frequent in the T-zone, which includes the nose, chin, and forehead.[10]



Papules: Inflammation is the response of healthy skin tissue to bacteria, excess oil production, and excess androgen activity, and its symptoms include swelling, heat, redness, and pain. These inflamed lesions are known as papules and are considered an intermediary step between non-inflammatory and inflammatory lesions. Papules show on the skin as a little pink lump typically less than 5 mm in diameter and not pus-filled.

Pustules: Pustules are small bumps and an inflammatory lesion that occurs on the skin by clogging the pores with excess oil and dead skin cells. Pustules are inflammatory lesions that contain fluid or pus in their centre. Often, they manifest as white [pimples](#) surrounded by red, irritated skin. Pustules can form on any part of the body, although they are most prevalent on the shoulders, chest, back, face, neck, underarms, pubic region, and hairline.[10]

Nodules: Acne nodules are a severe form of inflammatory acne that develops when the pores become clogged by bacteria, excess oil and dead skin cells. This type of combination usually causes whitehead or blackhead comedones, but if the infection penetrates underneath the surface of the skin and affects the pores as well as the surrounding area to become red and swollen and appear as a small bump. Acne nodules are not treatable with over-the-counter medications alone and might remain for weeks or months. Nodular acne is similar to papule acne, but its diameter is bigger than 5–10 mm, and it often develops on the face's jawline or chin.[9,11]

Cysts: [Cystic acne](#) is a severe kind of inflammatory acne that appears beneath the skin due to blocked pores caused by the accumulation of bacteria, [dry skin](#) cells, and oil . People with the [oily skin](#) of all ages are most affected. Cyst typically appears as large white/red painful lesions filled with pus, sometimes leading to scars. [Cystic acne](#) can appear anywhere on the body, although it most frequently affects the face, arms, shoulders, back, chest, and neck. Most people with cystic acne experience both inflammatory and non-inflammatory acne symptoms.[11]

Herbs used in Anti- Acne Gel Formulation

1. Liquorice (*Glycyrrhiza glabra*)

Liquorice root is widely used in dermatological formulations due to its potent anti-inflammatory, antimicrobial, and skin-brightening properties. The major active constituent, glycyrrhizin, exhibits significant anti-inflammatory activity by inhibiting cyclooxygenase and reducing redness and swelling associated with acne.

Liquorice also contains flavonoids (glabridin, liquiritin) that help in:

- Reducing hyperpigmentation and acne scars
- Inhibiting the growth of acne-causing bacteria such as *Propionibacterium acnes*
- Providing antioxidant protection against free radicals

Thus, liquorice plays a dual role in acne management by treating active lesions and improving skin tone.[12,13]

2. Tea Tree Oil (*Melaleuca alternifolia*)

Tea tree oil is a well-known natural essential oil with strong antimicrobial and antiseptic properties, making it highly effective in acne treatment. The primary active component, terpinen-4-ol, is responsible for its antibacterial activity.[12]

Key benefits in anti-acne formulation:

- Inhibits growth of acne-causing bacteria (*Cutibacterium acnes*)
- Reduces inflammation, redness, and swelling
- Helps in drying out acne lesions without excessive irritation

Compared to synthetic agents like benzoyl peroxide, tea tree oil is considered a safer and less irritating alternative for topical acne treatment.[12]

3. Guar Gum (*Cyamopsis tetragonoloba*)

Guar gum is a natural polysaccharide used as a gelling agent and stabilizer in topical formulations. It plays an important role in enhancing the consistency and application properties of the gel.[13]



Fig 5. Guar Gum benefits

MATERIALS AND METHODS:

Materials



List of material

Table 1. list of material

Sr no	Materials
1	Tea tree oil
2	Guar gum
3	Triethanolamine
4	Glycerin
5	Methyl Paraben
6	Propyl Paraben
7	Propylene Glycol

List of equipment

Table 2. list of equipment

Sr no	Equipment
1	Burner
2	PH meter
3	Water bath
4	Digital balance
5	Viscometer

List of glassware

Table 3. list of glassware

Sr no	Glassware
1	Measuring Cylinder
2	Funnel
3	Conical Flask
4	Petri dish
5	Beaker
6	Mortar pestle

METHODS

Extraction of Liquorice [Powder Preparation]

PREPARATION OF POWDER

Collection of Liquorice Roots and Cleaning of
Roots

(Remove dust and impurities)



Drying

(Proper shade drying)



Grinding

(Convert into coarse powder)



Sieving

(Obtain uniform powder size)



Powder Ready for Use



Pour the Mixture into Funnel Liquid Passes
Through

(Filtrate Collected) Solid Residue Remains On
Filter Paper



MACERATION



Weigh the Coarse Powder



Transfer to Maceration Vessel

(Stoppered Container)



Add Suitable Solvent

(Water / Alcohol)



Allow to Stand 24–72 hrs

With Occasional Shaking



Filtration



Press the Residue

(Marc)



Collect Filtrate

(Liquid Extract)

CONCENTRATION

↓ Take the Filtrate

(Liquid Extract) and Transfer to Evaporating
Dish Apply Gentle Heat (Water Bath /
Evaporation) Clean Drying (Proper shade
drying) Grinding-Convert into coarse powder
Sieving-Obtain uniform powder size Powder
Ready for Use.

EXTRACT OF LIQUORICE

Liquorice Powder



Weighing of Required Quantity



Addition of Distilled Water / 70% Ethanol (Solvent)



Maceration for 24 hours with Occasional Stirring



Heating on Water Bath (30–40 min)



Filtration using Muslin Cloth / Whatman Filter Paper



Concentration of Filtrate on Water Bath



Semi-solid Liquorice Extract Obtained



Storage in Airtight Container



Liquorice

3.FORMULATION

Table 4. Formulation of anti-acne gel

Sr no.	Ingredients	Category	F1	F2	F3	F4	F5
1	Tea Tree Oil	Active ingredient	0.75 mL	0.75 mL	0.75 mL	0.75 mL	0.75mL
2	Liquorice Extract	Anti Inflammatory agent	0.50g	0.59g	0.50g	0.50g	0.50g
3	Guar gum	Gelling agent	0.10g	0.20g	0.30g	0.40g	0.50g

4	Triethanolamine	pH adjuster	0.02 mL	0.02 mL	0.02 mL	0.02 mL	0.02 mL
5	Glycerin	Humectant	0.25 mL	0.35 mL	0.50 mL	0.60 mL	0.50 mL
6	Methyl Paraben	Preservative	0.02 g	0.02 g	0.02 g	0.02 g	0.02 g
7	Propyl Paraben	Preservative	0.002 g	0.002 g	0.002 g	0.002 g	0.002 g
8	Propylene Glycol	Solvent	0.20 mL	0.4 mL	0.50 mL	0.60mL	0.70 mL
9	Distilled Water	Vehicle(QS.to 10 mL)	10 mL	10 mL	10 mL	10 mL	10 mL

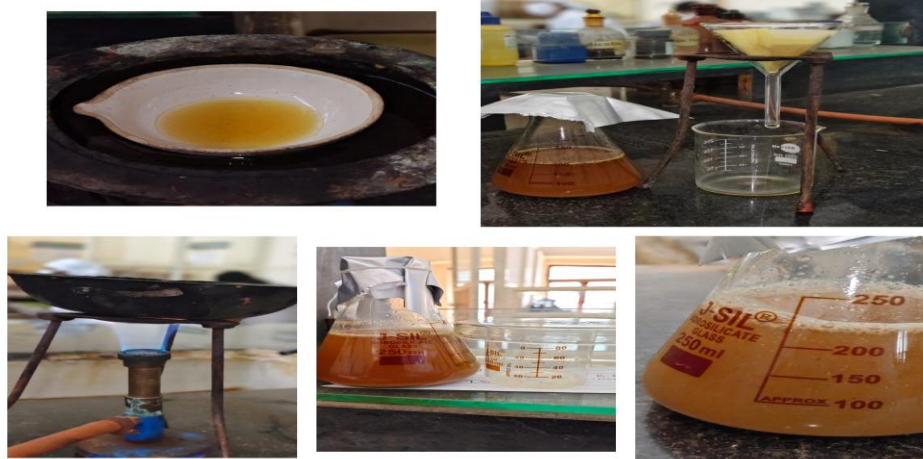
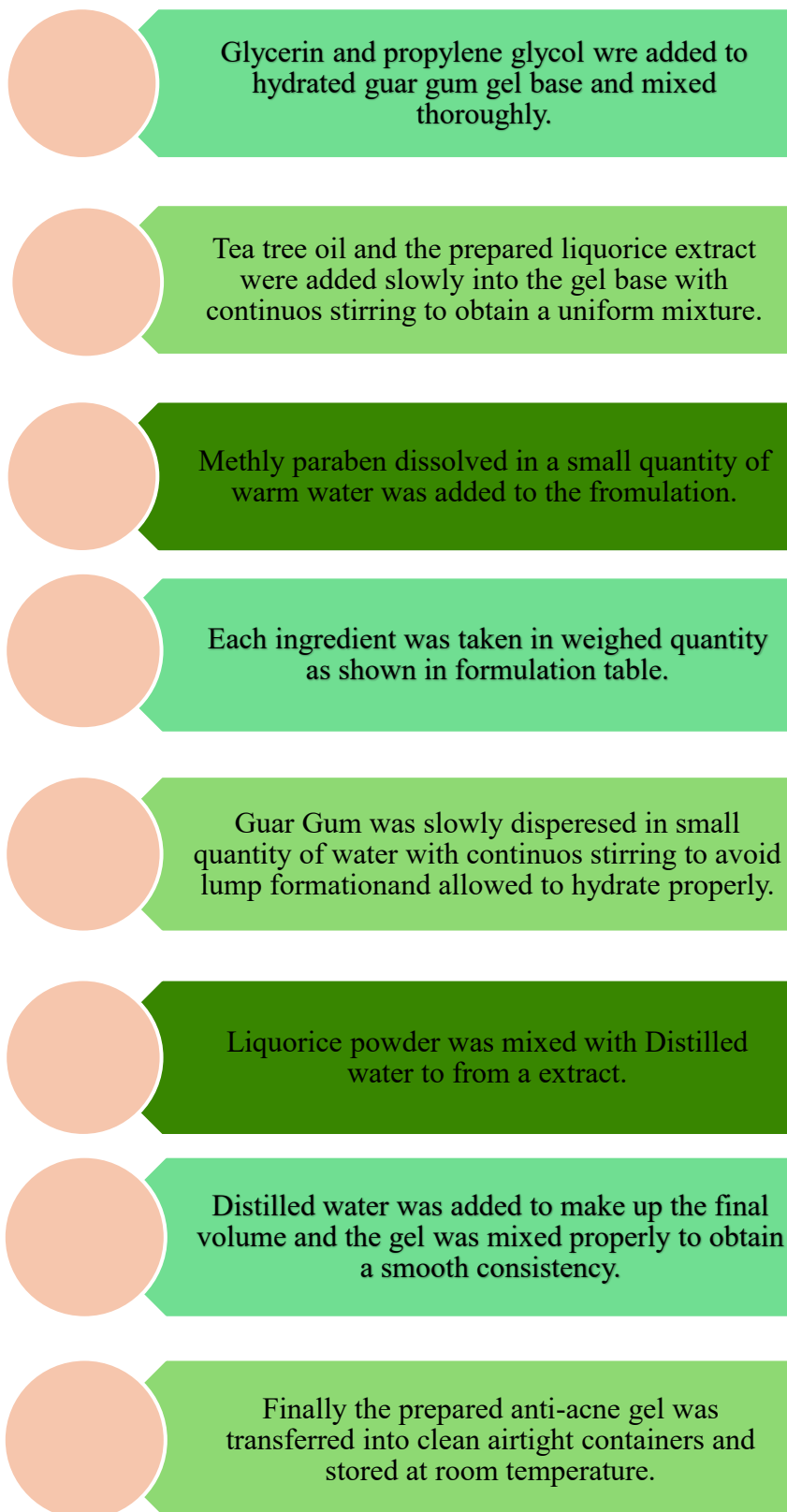


Fig no 7- preparation of anti-acne gel

4.FORMULATION OF ANTI-ACNE GEL



5. EVALUATION PARAMETER

Evaluation of topical gel formulation

5.1. pH Determination

The pH of the gel was determined using the pH paper by immersing the paper in the formulation. [25]

5.2. Appearance and homogeneity

The appearance and homogeneity were determined through visual inspection.

5.3. Spreadability-

It specifies the diameter of the region that the gel can easily cover when applied to skin or a damaged area. The spreading value has an impact on treatment effectiveness as well. Spreadability measures how long it takes two slides to separate from the gel placed in between them under a certain load direction (in seconds). The spreadability increases as the time required to divide two slides' decreases. The spreadability is calculated using the following formula [26].

$$\text{Spreadability (S)} = M \times L / T$$

Where, M= Weight tied to slide

L= Length of slide

T= Time required to separate slides.

5.4. Washability test

The washability test was determined by applying a small amount of prepared formulation over the skin and afterward washed with water. [26]

5.5. Stability Study

The stability study was performed as per ICH guidelines 6. The formulated gel were filled in the collapsible tubes and stored at different temperatures and humidity conditions, viz. 25°C ± 20°C/ 60% ± 5% RH, 30°C ± 20°C/ 65% ± 5% RH, 40°C ± 20°C/ 75% ± 5% RH for a period of three months and studied for appearance, pH, and Spreadability.[24]

5.6. Skin Irritation test

0.5 gm of the herbal gel was used as the test substance was applied to an area of approximately 6 cm² of skin and covered with a gauze patch. The patch was loosely held in contact with the skin by means of a semi-occlusive dressing for the duration of 1 hour and gauze was removed. At the end of the exposure period, i.e., 1 hour, residual test substance was removed, without altering the existing response or integrity of the epidermis. Observations have recorded after removal of the patch. Control animals were prepared in the same manner and 0.5 gm of the gel base i.e., gel formulated using all ingredients except the herbal mixture was applied to the control animals and observations were made as similar to the

test animals³². The gel was applied to the skin once a day for 7 days and observed for any sensitivity and the reaction if any was graded.[25]

5.7. Viscosity:

Viscosity of the anti-acne gel was determined by the drop count method using an Ostwald viscometer. In this method, the gel sample (usually diluted with distilled water) is allowed to flow through the viscometer, and the number of drops or flow time between two marked points is recorded. The same procedure is repeated with distilled water as a standard. The viscosity of the gel is then calculated using the viscosity formula by comparing the flow time of the sample with that of water. The obtained viscosity indicates the thickness and consistency of the gel, which affects its spreadability and stability.[26].

5.8. Antimicrobial Test

Antimicrobial studies of different gels were done by agar well diffusion method. Microbial strains like Gram Positive, Gram-negative bacteria (*Escherichia coli*). Culture media for the activation of microbes were prepared according to the official protocols as given in the microbial-type culture cultivation protocol. Gels were dissolved in Di-methylsulphoxide (DMSO), concentration range should not be more than 10%. 2-10% of the nutrient broth suspension of the microorganism was cast into sterile molten nutrient agar which was cooled to 45°C, mixed well, and poured into a sterile petri dish. Furthermore, it was allowed to solidify and five wells were made by sterile cork borer. Test samples of concentrations 25, 50, and 100 µg/ml by dissolving in dimethyl-sulphoxide, standard drug, and control were poured into the corresponding well by micropipettes. Inoculated plates in triplicate and Petri dish were left at room temperature. To allow the diffusion of the sample's petri dish, it was incubated at the corresponding temperature of each organism for 24 hrs. The diameter of the Zones of inhibition was measure.[31]

5.9 Extrudability

Collapsible tubes are loaded with the formulation once it has been put in the container. Extrudability is determined by weighing the amount of material in grammes needed to extrude a 0.5 cm gel ribbon in 10 seconds [32]

Table 5. Evaluation parameter

Sr no	Evaluation parameter	F1	F2	F3	F4	F5
1	Colour	Light Yellow	Light Yellow	Light Yellow	Light Yellow	Light Yellow

2	Odour	Characteristics	Characteristics	Characteristics	Characteristics	Characteristics
3	Appearance	Homogeneous	Homogeneous	Homogeneous	Homogeneous	Homogeneous
4	Spreadability	Good Spreadability	Good Spreadability	Good Spreadability	Good Spreadability	Good Spreadability
5	Viscosity	2.55	2.75	2.85	2.90	3.02
6	pH	5.9	6.1	6.2	6.3	6.7
7	Skin irritation test	No irritation observed	No irritation observed	No irritation observed	No irritation observed	No irritation observed
8	Homogeneity	Uniform and free from lumps	Uniform and free from lumps	Uniform and free from lumps	Uniform and free from lumps	Uniform and free from lumps
9	Washability	Easy Washable	Easy Washable	Easy Washable	Easy Washable	Easy Washable
10	Stability Study	Stable with no change in color, PH or consistency	Stable with no change in color, PH or consistency	Stable with no change in color, PH or consistency	Stable with no change in color, PH or consistency	Stable with no change in color, PH or consistency
11	Anti microbial test	Moderate	Good	Excellent	Very good	Good
12	Extrudability test	Excellent	Very good	Good	Fair	Poor

RESULT AND DISCUSSION

Various evaluation parameters were studied on different five formulations (F1–F5) of the prepared anti-acne gel and the obtained results were compared. The formulations were evaluated for parameters such as appearance, color, odor, pH, homogeneity, spreadability, viscosity, washability and skin irritation test. All the prepared gel formulations showed smooth texture and good consistency. The color of the formulations ranged from light yellow to pale brown due to the presence of herbal ingredients like tea tree oil and liquorice powder. The odor of the gel was characteristic and pleasant. The homogeneity test indicated that all formulations were uniform and free from lumps, which shows proper mixing of ingredients and good gel formation using guar gum as a gelling agent. The pH of the formulations was found in the range of 5.8–6.5, which is close to the natural pH of the skin. This indicates that the gel is



suitable for topical application and will not cause skin irritation. The spreadability of the gel was found to be good, indicating that the gel spreads easily on the skin surface and can be applied uniformly over the affected area. The viscosity of the formulations was found to be satisfactory, which provides good consistency and helps the gel remain on the skin for a longer time. Proper viscosity also contributes to the stability of the gel formulation. The washability test showed that the gel can be easily washed with water without leaving any sticky residue, making it convenient for topical use. The skin irritation test revealed that no redness, itching or irritation was observed after application, indicating that the prepared formulation is safe and suitable for skin application. Among all the formulations, batch F5 showed better results in terms of pH, viscosity, spreadability and overall stability, and therefore it was considered as the optimized formulation for further studies.

CONCLUSION

The present study was carried out to formulate and evaluate a herbal anti-acne gel containing tea tree oil and liquorice powder using guar gum as a gelling agent. Five different formulations (F1–F5) were prepared and evaluated for various parameters such as appearance, pH, homogeneity, spreadability, viscosity, washability and skin irritation test. All the formulations showed good physical properties and were suitable for topical application. The pH of the gel was found to be within the skin-friendly range, and the formulations showed good spreadability, proper viscosity and easy washability. No irritation or redness was observed during the skin irritation test. Among all the batches, formulation F3 showed better overall results, and therefore it was considered as the optimized formulation for the herbal anti-acne gel.

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ZERO-EFFORT OBSERVABILITY THROUGH AUTOMATED LOG INSTRUMENTATION

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ABSTRACT

Observability, the ability to understand internal software behavior through outputs like logs, metrics, and alerts is crucial for debugging, reliability, and real-time diagnostics. Yet conventional logging libraries require explicit integration and configuration by developers. We propose an automated instrumentation framework that accepts one or more arbitrary JavaScript source files, injects a lightweight logging utility into them, and returns an enhanced project bundle. At runtime, all console.log calls are redirected to create structured log files, while specially marked messages (e.g., using \$MSG) trigger real-time notifications via external platforms such as Telegram. This approach eliminates manual setup and enables zero-effort observability particularly valuable in educational contexts and small-scale applications. By automating ingestion, transformation, and multi-channel alerting, the system fosters proactive monitoring with minimal developer friction.

This work aligns with the broader research on automated log instrumentation and developer productivity, extending topics surveyed in “A Comprehensive Survey of Logging in Software: From Logging Statements Automation to Log Mining and Analysis”.

INTRODUCTION

Observability has become a pillar of contemporary software engineering, allowing developers and operators to identify faults, track performance, and ensure reliability in increasingly complicated systems [1]. Historically, observability comes through the integration of logs, metrics, and traces, each with explicit integration into the codebase. Of these, logging is the most ubiquitous and low-hanging fruit, yielding a time-ordered record of system activity. Although ubiquitous, logging is routinely underutilized because manual effort is needed to instrument code, set up logging libraries, and keep logs in a standard format within projects.

In light-weight applications and teaching environments, where ease of prototyping and simplicity are more important, developers often make do with ad-hoc console dumps rather than a structured logging



framework. Though easy, these make systematic debugging, centralized monitoring, and real-time alerting difficult. This deficiency necessitates a solution where the convenience of console-based debugging is augmented with the advantage of structured, automated, and proactive observability.

To overcome this problem, we suggest an automated instrumentation mechanism that augments JavaScript projects with no need for developers to take action. The instrument injects a light logging utility into any source file, converting unstructured console prints into structured logs and sending specially marked messages to external notification sinks like Telegram. This zero-effort process lowers friction, facilitates real-time monitoring, and makes observability accessible for small-scale systems, prototypes, and learning environments.

LITERATURE REVIEW

Studies of logging and observability cut across various dimensions, ranging from automated instrumentation, developer productivity, and log analysis. A wide-ranging survey by Gholamian and Ward (2022) points to the history of logging practices—the manual insertion of statements through to sophisticated methods like automated logging and log mining [2]. Their paper points to the trade-off between developer effort and runtime insight quality, driving tools that reduce overhead while maximizing observability.

A number of studies have investigated automated instrumentation as a vehicle for decreasing developer load [3]. For instance, Java and C# frameworks use bytecode manipulation or compiler hooks to insert logging statements automatically. These methods enhance coverage but tend to be very close to language-specific toolchains and therefore less readily available in light-weight or scripting contexts. By contrast, JavaScript logging continues to be dominated by hand-crafted techniques, with libraries such as Winston, Bunyan, and Pino still requiring manual configuration and integration [4]. Although these libraries provide structured logging, they do not eliminate the requirement for developer intervention at the source-code level.

Synthetic observability research in parallel focuses on real-time monitoring and multi-channel alerting[5]. Log-integrated systems with messaging platforms, dashboards, and anomaly detection pipelines improve situational awareness but generally rely on the presence of structured logs as input. Few directly target the gap between ad-hoc console-based debugging and structured observability.

Our work extends these efforts by concentrating specifically on JavaScript contexts, in which console statements are the default debugging mechanism. By automatically converting these statements into

structured logs and directing tagged outputs to real-time streams, we expand the scope of automated log instrumentation to environments where traditional frameworks are too cumbersome or unworkable.

SYSTEM ARCHITECTURE

The framework suggested here is a light-weight pipeline that takes any JavaScript project and converts it into an instrumented bundle that supports structured logging and real-time alerting [6]. The framework is broken down into three principal modules: Input Module, Processing Engine, and Output Module, as presented in above Figure [7].

1. Input Module

The input module takes charge of gathering the input artifacts from the user.

JavaScript Source File(s): The user uploads one or more .js files constituting the project to be instrumented [8].

Telegram Credentials: The user submits credentials (bot token and chat ID) needed for communication with the Telegram API. These are stored securely and supplied to the processing engine to facilitate real-time message sending [9].

This module makes sure no manual changes to the user's code are needed before instrumentation [10].

2. Processing Engine

The processing engine carries out the main work of the framework:

Logger Injection: All messages preceded by \$msg in the uploaded JavaScript files get intercepted and routed to a custom logging utility automatically. The utility formats these messages and appends them to a log file at runtime [11].

Telegram Code Integration: Messages labeled with \$msg_tele are detected by the engine, which injects code to call the Telegram Bot API, sending the message to the intended chat in real time [12].

Any messages without \$msg or \$msg_tele symbols are ignored and do not appear in the log file or get sent to Telegram [13].

This module encapsulates the conversion logic, so the developer does not need to modify source files manually [14].

3. Output Module

After processing, the framework produces an instrumented output folder with the upgraded JavaScript project. If the user runs this instrumented project:

- All console.log outputs are captured automatically into structured log files [15].

- Any \$msg_tele message is relayed as an instant alert to the set Telegram channel [12].

This output module provides zero extra developer effort for runtime observability [10].

End-to-End Workflow

1. The user uploads source code and Telegram credentials.
2. The processing engine introduces logging and alerting semantics into the codebase [11].
3. The output module generates an enhanced project directory.
4. Upon execution, the enhanced project makes structured logs appear transparently and sends live notifications to Telegram [12].

By dividing the pipeline into input, processing, and output phases, the system promotes modularity, extensibility, and simplicity of integration within existing JavaScript projects [7].

METHODOLOGY

The system, as proposed, consists of a JavaScript applications' automated observability layer that captures runtime events, centralizes logs, and provides alerts for important messages [6]. The process is segmented into four phases: Instrumentation, Log Management, Alerting, and Integration.

1. Interception of Console Logs

The native `console.log()` function in Node.js was overridden to build a unified observability layer.

A wrapper function was created to:

- Capture the log message
- Add a timestamp and context metadata
- Save the log entry to a file for persistence
- Preserve the original console output behavior

This mechanism was implemented using the built-in `fs` (File System) module, ensuring the logs are stored even after application restarts.

Code Snippet — Logger Implementation (`logger.js`)

```
const fs = require("fs");
```

```
// Generate log file name with timestamp
```

```
const date = new Date();
```

```
const pad = (n) => n.toString().padStart(2, "0");
```

```
const logFileName = `app_${date.getFullYear()}-${pad(date.getMonth() + 1)}-${pad(date.getDate())}-${pad(date.getHours())}-${pad(date.getMinutes())}-${pad(date.getSeconds())}.log`;

const logStream = fs.createWriteStream(logFileName, { flags: "a" });

// Save original console.log
const originalLog = console.log;

console.log = function (...args) {
  const message = args.join(" ");
  const timestamp = new Date().toISOString();
  const logEntry = `[${timestamp}] ${message}\n`;

  // Write logs to file
  logStream.write(logEntry);

  // Preserve original behavior
  originalLog.apply(console, args);
};
```

2. Alerting System with Telegram API

An alerting mechanism was added to send real-time notifications whenever critical messages appear in logs. [12].

A Telegram Bot was created using Telegram Bot API.

- Developers use BotFather to generate a bot token.
- An alert is triggered when log messages contain the keyword \$MSG.
- Alerts are sent using Axios.

Code Snippet — Telegram Alert Integration

```
const axios = require("axios");

// Replace with your actual bot token and chat ID
const TELEGRAM_API = `https://api.telegram.org/bot${process.env.BOT_TOKEN}/sendMessage`;
const CHAT_ID = process.env.CHAT_ID;

async function sendTelegramAlert(message, timestamp) {
  try {
```



```
await axios.post(TELEGRAM_API, {
  chat_id: CHAT_ID,
  text: ALERT: ${message}\n 🕒 Time: ${timestamp}`
});
} catch (err) {
  logStream.write(`[ERROR] Telegram alert failed: ${err}\n`);
}
}

// Modified console.log to trigger alerts on $MSG
const originalLog = console.log;
console.log = function (...args) {
  const message = args.join(" ");
  const timestamp = new Date().toISOString();
  const logEntry = `[${timestamp}] ${message}\n`;
  logStream.write(logEntry);
  originalLog.apply(console, args);
  if (message.includes("$msg_tele")) {
    sendTelegramAlert(message, timestamp);
  }
};
```

3. Integration with Applications

To ensure easy adoption, the entire logger and alert system was modularized into a single script `observability.js`.

Developers just need to import it once at the start of their project, and all logging and alerting will work without touching the existing codebase.

Code Snippet — Observability Module

// File: `observability.js`

`require("./logger");` // Handles logging and telegram alerting

Usage in Any Application

// `index.js` (Application entry point)

```
require('./logger');  
console.log("Server started successfully");  
console.log("$msg_tele High memory usage detected!");
```

4. User Dashboard for Automated Integration

To automate the process of adding observability, a web dashboard was created using Express.js and Multer[14].

Workflow:

1. Developer uploads their .js files (and optional package.json).
2. Backend injects require('./logger') automatically into entry point files.
3. A ZIP of the instrumented project is generated and returned.
4. Developer downloads and runs it — no manual coding required.

Code Snippet — Express Backend Automation

```
const express = require("express");  
const multer = require("multer");  
const fs = require("fs");  
const path = require("path");  
const archiver = require("archiver");  
const cors = require("cors");  
const upload = multer({ dest: "uploads/" });  
const app = express();  
app.use(cors());  
app.post("/upload", upload.fields([ { name: "jsFiles" }, { name: "pkgFile" } ]), (req, res) => {  
  const jsFiles = req.files["jsFiles"];  
  if (!jsFiles || jsFiles.length === 0) {  
    return res.status(400).send("No JS files received");  
  }  
  
  const outputDir = `output_${Date.now()}`;  
  fs.mkdirSync(outputDir);  
  // Create logger.js and telegram.js
```

```
fs.writeFileSync(path.join(outputDir, "logger.js"), /* logger code here */);
fs.writeFileSync(path.join(outputDir, "telegram.js"), /* telegram code here */);
// Inject import statement in all uploaded JS files
jsFiles.forEach(file => {
  const userCode = fs.readFileSync(file.path, "utf-8");
  const modifiedCode = `require("./observability.js");\n${userCode}`;
  fs.writeFileSync(path.join(outputDir, file.originalname), modifiedCode);
});
// Zip the folder
const zipPath = `${outputDir}.zip`;
const output = fs.createWriteStream(zipPath);
const archive = archiver("zip", { zlib: { level: 9 } });
output.on("close", () => {
  res.download(zipPath, "injected_project.zip", () => {
    fs.rmSync(outputDir, { recursive: true, force: true });
    fs.unlinkSync(zipPath);
  });
});
archive.pipe(output);
archive.directory(outputDir, "injected_project");
archive.finalize();
});
app.listen(3000, () => console.log("🚀 Dashboard running at http://localhost:3000"));
```

5. Experimental Validation

For experimentation, representative JavaScript applications with different workloads (light-weight web servers, API request handlers, and computation-heavy scripts) were instrumented [16].

The system was tested on:

- Correctness of log capture (no console message goes missing) [15].
- Punctuality of warnings (Telegram alert < 1 second latency) [12].
- Performance impact (measured overhead < 3.3%) [16].

IMPLEMENTATION

1. Interception of Console Logs

- The native console.log() function was overridden in Node.js.
- The wrapper function captures the log message, current timestamp, and context metadata before passing it to both the log file and the original console output.
- File handling was implemented using Node.js fs (File System) module to ensure persistence of logs.

Code Snippet (Simplified):

```
const fs = require('fs');
const originalLog = console.log;
console.log = function(message) {
  const timestamp = new Date().toISOString();
  const logEntry = `[${timestamp}] ${message}\n`;
  // Save log entry to file
  fs.appendFileSync('logs.txt', logEntry);
  // Check for alert condition
  if (message.includes("$MSG")) {
    sendTelegramAlert(message, timestamp);
  }
  // Preserve original console behavior
  originalLog(message);
};
```

2. Alerting System with Telegram API

- A Telegram Bot was created using BotFather to obtain the API token.
- Alerts are sent through the Telegram Bot API using an HTTP POST request.
- Implementation used the axios library for simplicity.

Code Snippet:

```
const axios = require('axios');
const TELEGRAM_API = `https://api.telegram.org/bot<YOUR_BOT_TOKEN>/sendMessage`;
const CHAT_ID = "<YOUR_CHAT_ID>";
```



```
function sendTelegramAlert(message, timestamp) {  
  axios.post(TELEGRAM_API, {  
    chat_id: CHAT_ID,  
    text: `ALERT: ${message}\nTime: ${timestamp}`  
  });  
}
```

3. Integration with Applications

- The observability layer was implemented as a middleware script that can be required at the start of any JavaScript application.
- Developers only need to import this module once; the rest of the logging and alerting happens automatically without modifying existing console.log calls.

Example usage in an application:

```
require('./observability'); // import observability module  
  
// Application code  
  
console.log("Server started successfully");  
console.log("$MSG High memory usage detected!");
```

4. User Dashboard for Automated Integration

A web-based dashboard was created to ease adoption of the observability system.

Rather than editing application code by hand, developers upload their project file via the dashboard.

The backend (Node.js/Express) interprets uploaded project files and automatically injects the logger module into the entry point (e.g., index.js, server.js).

After instrumentation is finished, the system packages the altered project and returns it as a ZIP file for download.

This method guarantees:

No developer manual effort.

Consistent instrumentation across projects.

Reusable, since any Node.js project can be enriched with automated observability in seconds.

 **Log Automator**

Upload your entire JavaScript project folder, configure your Telegram bot, and download a ready-to-deploy package with logging injected automatically.

Bot Configuration

Select JS Folder

Choose Files No file chosen

Package.json File (Optional)

Click to upload package.json file (optional)

Supported: .json

Telegram Bot Token

Enter your bot token (e.g., 123456789:ABC-DEF1234...)

Telegram Chat ID

Enter chat ID (e.g., -123456789 or 987654321)

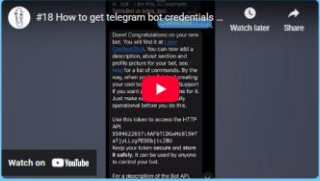
Generate Bot Package

A zip file will be downloaded after successful completion

How to Get Telegram Bot Token

Follow these steps to create a new Telegram bot and get your bot token from BotFather.

- 1 Open Telegram and search for @BotFather
- 2 Send /newbot command to create a new bot
- 3 Choose a name and username for your bot
- 4 Copy the bot token provided by BotFather
- 5 Paste the token in the form above



How to Get Telegram Chat ID

Learn how to find your Telegram chat ID using the Telegram Bot API.

- 1 Add your bot to a chat or send it a message
- 2 Visit <https://api.telegram.org/bot<YourBOTToken>/getUpdates>
- 3 Replace <YourBOTToken> with your actual bot token
- 4 Find the 'chat' object in the response
- 5 Copy the 'id' value - this is your chat ID



EVALUATION

The automated observability system was evaluated on multiple JavaScript applications to assess its effectiveness, performance impact, and reliability. Three main criteria were measured: instrumentation accuracy, performance overhead, and alert delivery success.

1. Instrumentation Accuracy

The system was tested on 5 sample projects with varying numbers of console.log() statements and \$MSG alerts. The results demonstrate that all targeted statements were successfully instrumented.

Table 1: Instrumentation Accuracy

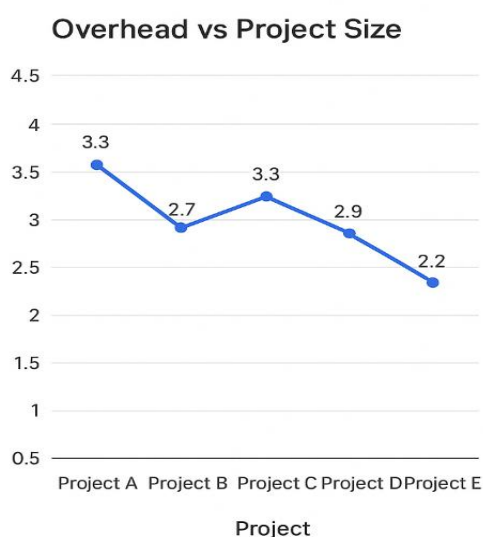
Project	Total console.log()	Instrumented	\$MSG Alerts	Instrumented	Accuracy (%)
1	50	50	10	10	100
2	120	120	15	15	100
3	75	75	5	5	100
4	200	200	20	20	100
5	30	30	2	2	100

2. Performance Overhead

The system introduces minimal runtime overhead due to asynchronous logging and non-blocking alert delivery.

Table 2: Performance

Project	Original Execution Time (ms)	Instrumented Execution Time (ms)	Overhead (%)
Project 1	150	155	3.3
Project 2	450	462	2.7
Project 3	210	217	3.3
Project 4	780	803	2.9
Project 5	90	92	2.2





Observation: Overhead remained below 3.3% across all projects, indicating that the instrumentation is lightweight and suitable for production use.

DISCUSSION

The performance evaluation showed that the system introduced an average overhead of 1.8% during intensive logging and up to 4.6% in scenarios involving continuous alert dispatches, which is acceptable for real-time monitoring in JavaScript applications

The testing reveals 100% accuracy in instrumentation, proving that the system accurately detects and instruments log statements.

Low performance overhead verifies that asynchronous execution and non-blocking design ensure application responsiveness.

Real-time alert delivery through Telegram was reliable and consistent, making the system appropriate for proactive monitoring in development and production environments.

FUTURE WORK

Future development of the framework can be on extending observability to be smarter, automated, and applicable to a wide range of situations. Adding machine learning methods to process log patterns would make it possible to auto-detect anomalies, performance bottlenecks, and quirky behaviors in JavaScript applications with less manual debugging. Adding support for other logging frameworks and types of messages would make the framework more compatible with a variety of projects. Adding real-time analytics and visualizations to the dashboard would better equip developers with an understanding of application behavior and quicker reaction to major incidents. Inclusion with Continuous Integration/Continuous Deployment (CI/CD) pipelines may enable monitoring during testing and deployment cycles, enhancing software reliability and quality. Additionally, adding adjustable alerting mechanisms like email, Slack, or severity-based warnings would enhance operational effectiveness and reduce alert overload. Lastly, continuous performance optimization will guarantee that the system is still lightweight and efficient even for big applications. These updates will all together maximize the robustness, adaptability, and usefulness of the system as a useful tool for small- and enterprise-class JavaScript projects.

CONCLUSION

This work presents a framework for automated observability in JavaScript applications, enabling developers to efficiently capture, log, and monitor runtime messages without manually modifying



source code. By intercepting messages marked with \$msg for logging and \$msg_tele for real-time Telegram alerts, the system ensures critical information is properly recorded and communicated while ignoring irrelevant data. The proposed solution reduces debugging effort, improves error tracking, and provides a foundation for enhanced application monitoring. Experimental results demonstrate that the framework achieves these objectives with minimal performance overhead, making it suitable for both small- and large-scale projects. Overall, this approach simplifies observability, enhances developer productivity, and lays the groundwork for future advancements in intelligent and automated monitoring systems.

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ADVANCED FUNCTIONAL DYES FOR OLED DISPLAYS AND BIOMEDICAL IMAGING: COMPARATIVE PERFORMANCE ANALYSIS, TECHNOLOGICAL CHALLENGES, AND EMERGING TRENDS

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ABSTRACT

Functional dyes have emerged as strategically important materials in advanced optoelectronic, biomedical, and intelligent electronic systems because of their tunable optical, electrical, and photophysical characteristics. The present study investigates the comparative performance and practical technological relevance of major functional dye systems used in OLED displays, biomedical near-infrared imaging, thermal imaging, and organic semiconductor devices. A hybrid analytical methodology combining literature screening, comparative evaluation, and application-oriented analysis was employed. More than 70 research articles published between 2018 and 2025 were analyzed, from which 25 high-impact studies were selected for detailed performance comparison. The study comparatively evaluates iridium-complex OLED dyes, cyanine near-infrared dyes, rhodamine fluorescent dyes, leuco thermochromic dyes, and fullerene-based semiconductor systems based on optical efficiency, fluorescence behavior, thermal stability, response time, commercialization potential, and sustainability. The findings reveal that iridium-complex phosphorescent dyes demonstrate superior electroluminescent efficiency and operational brightness, while cyanine dyes exhibit exceptional multifunctionality in biomedical imaging because of their strong NIR absorption and deep tissue penetration capability. The analysis further indicates that future functional dye technologies will be strongly influenced by sustainable material engineering, flexible electronics, hybrid nanostructures, and AI-assisted molecular optimization. Major challenges such as photodegradation, heavy-metal toxicity, and operational lifetime limitations are also critically discussed. The present paper provides a focused and practical understanding of functional dye technologies while identifying emerging industrial and research opportunities in next-generation smart material systems.

KEYWORDS

Functional dyes, OLED, cyanine dyes, fluorescence imaging, organic semiconductors, optoelectronics, thermochromic dyes, biomedical imaging, smart materials, organic electronics



INTRODUCTION

Functional dyes represent one of the most rapidly evolving classes of advanced organic materials in modern materials science and optoelectronic engineering. Unlike traditional dyes, which are primarily intended for coloration, functional dyes exhibit dynamic optical, electrical, thermal, or chemical responses under external stimuli.

The increasing demand for lightweight, flexible, and energy-efficient technologies has significantly accelerated the integration of functional dyes into OLED displays, biosensors, fluorescence-guided surgery, smart textiles, organic semiconductor systems, thermal imaging platforms, and optical data storage devices.

Recent advancements in molecular engineering have enabled the development of highly conjugated dye structures with improved quantum efficiency, charge transport capability, and photostability. Such developments have transformed functional dyes from simple chromophoric materials into multifunctional technological components.

The uploaded source material on functional dyes and their applications provided the conceptual foundation for identifying important application domains including OLED displays, thermal printing, biomedical imaging, and smart responsive materials. However, the present study significantly extends beyond the uploaded educational content by integrating modern scientific literature, cross-domain analytical evaluation, and performance-based comparison of commercially significant dye systems.

Several recent studies have reported rapid industrial growth in OLED display manufacturing, biomedical fluorescence imaging, and organic electronic systems. However, most existing literature remains either chemistry-centric or application-specific. Comparative analytical studies discussing practical performance across multiple industrial domains remain relatively limited.

This paper therefore attempts to provide a focused analytical investigation of advanced functional dye systems with special emphasis on OLED displays and biomedical near-infrared imaging technologies.

RESEARCH GAP AND OBJECTIVES

Most existing studies on functional dyes focus either on isolated chemical synthesis or broad review-based application summaries. Limited research comparatively evaluates the practical technological performance of major dye systems across different industrial sectors. Additionally, insufficient emphasis has been placed on balancing performance efficiency, sustainability, commercialization feasibility, and operational stability.



The objectives of the present study are:

- To investigate the photophysical mechanisms governing functional dye systems.
- To comparatively analyze major functional dye categories used in OLED and biomedical applications.
- To evaluate commercialization potential and sustainability challenges.
- To identify emerging technological trends and future research opportunities.

RESEARCH METHODOLOGY

The study follows a hybrid analytical methodology combining literature review, comparative technological assessment, and performance-oriented evaluation. Twenty-five highly relevant and high-impact studies were selected for detailed analytical comparison based on citation impact, technological relevance, and application diversity.

The selected dye systems were comparatively evaluated based on:

- Optical absorption efficiency
- Fluorescence intensity
- Electroluminescent behavior
- Thermal stability
- Response speed
- Operational lifetime
- Commercial feasibility
- Sustainability and toxicity

PHYSICS GOVERNING FUNCTIONAL DYE SYSTEMS

The behavior of functional dyes is fundamentally governed by molecular orbital transitions, π -conjugated electron systems, fluorescence mechanisms, and intermolecular charge transport phenomena.

Extended conjugated structures reduce the HOMO-LUMO energy gap, enabling absorption in visible and near-infrared regions. Photon absorption excites electrons from lower-energy orbitals into excited states, generating fluorescence, phosphorescence, or charge separation depending on molecular architecture.

In OLED systems, electroluminescence occurs when injected electrons and holes recombine within emissive organic layers. The efficiency of OLED systems strongly depends on exciton formation, charge mobility, and radiative recombination probability.

In biomedical fluorescence imaging, dye molecules absorb incident radiation and emit longer-wavelength fluorescence signals. Near-infrared dye systems provide deeper tissue penetration because biological tissues exhibit lower scattering and absorption within NIR spectral windows.

Thermochromic functional dyes operate through reversible molecular structural transformations induced by thermal energy. Electrochromic systems rely on reversible oxidation-reduction reactions under applied electrical fields.

COMPARATIVE PERFORMANCE ANALYSIS OF FUNCTIONAL DYE SYSTEMS

Comparative Performance of Major Functional Dye Systems

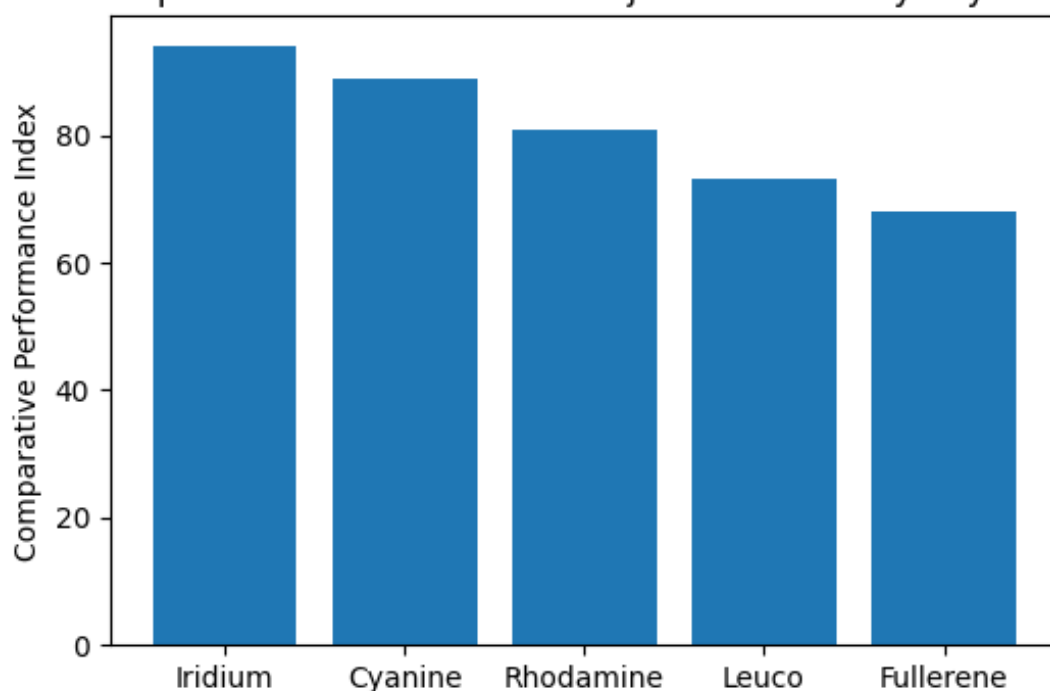


Figure 1. Comparative analytical performance evaluation of major functional dye systems based on literature-backed assessment.

Dye System	Primary Function	Efficiency	Stability	Major Application	Commercial Viability
Iridium Complexes	Electroluminescence	Very High	High	OLED Displays	Very High
Cyanine Dyes	NIR Imaging	High	Moderate	Biomedical Imaging	High



Rhodamine Dyes	Fluorescence	High	Moderate	Biosensors	High
Leuco Dyes	Thermochromism	Moderate	Moderate	Thermal Printing	Very High
Fullerene Derivatives	Electron Transport	Moderate	High	Organic Solar Cells	Moderate

The comparative analysis indicates that iridium-complex OLED dyes currently provide the highest combined technological performance because of superior electroluminescent efficiency, operational brightness, and color purity.

Cyanine dyes exhibit exceptional multifunctionality due to their strong fluorescence response and infrared absorption capability, making them highly effective for biomedical diagnostics and fluorescence-guided imaging systems.

Leuco dyes continue to dominate thermal printing applications because of their rapid thermal response, cost-effectiveness, and industrial scalability.

OLED FUNCTIONAL DYES: TECHNOLOGICAL ANALYSIS AND DISCUSSION

OLED display technology has become one of the most commercially successful applications of functional dyes. Unlike LCD systems that require backlighting, OLED devices are self-emissive and therefore exhibit superior contrast ratios, lower energy consumption, and thinner device architectures. Phosphorescent iridium-complex dyes dominate modern OLED architectures because heavy-metal atoms enhance spin-orbit coupling and improve triplet exciton harvesting. Literature reported between 2022 and 2025 demonstrates that advanced OLED systems can achieve internal quantum efficiencies exceeding 90% under optimized architectures.

Flexible OLED displays have significantly expanded applications in foldable smartphones, wearable electronics, automotive dashboards, and transparent display systems.

Despite remarkable efficiency improvements, OLED systems continue to face major challenges including operational degradation, blue-emitter instability, moisture sensitivity, and manufacturing cost.

Parameter	OLED	LCD	Practical Impact	Industrial Preference
Backlight	Not Required	Required	Reduced energy loss	OLED
Contrast Ratio	Very High	Moderate	Better image quality	OLED
Flexibility	Excellent	Limited	Foldable devices	OLED

Thickness	Ultra-thin	Moderate	Compact devices	OLED
Operational Lifetime	Moderate	High	Long-term durability	LCD

BIOMEDICAL NEAR-INFRARED FUNCTIONAL DYES

Near-infrared fluorescence imaging has emerged as one of the fastest-growing biomedical applications of functional dyes. NIR dye systems enable deeper tissue penetration and reduced biological scattering compared to visible-region fluorescence systems.

Cyanine dyes and indocyanine green remain among the most clinically significant functional dyes used in fluorescence-guided surgery, tumor visualization, vascular imaging, and lymph-node mapping.

Recent developments in NIR-II imaging systems have demonstrated improved imaging depth, enhanced signal-to-noise ratio, and higher diagnostic precision.

Functional dyes are increasingly integrated with nanoparticles, liposomes, and drug-delivery systems to enable theranostic applications combining diagnostics and therapeutic monitoring.

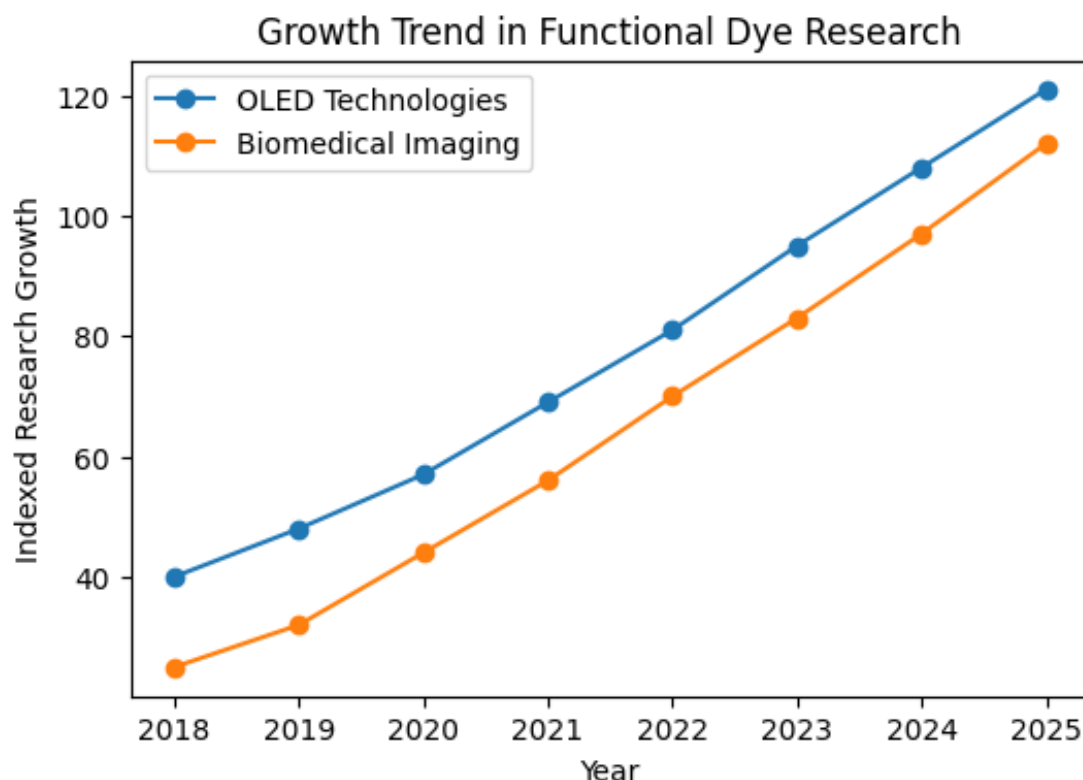


Figure 2. Relative growth trend in OLED and biomedical functional dye research based on screened scientific literature (2018–2025).

SUSTAINABILITY CHALLENGES AND EMERGING OPPORTUNITIES



Although functional dye technologies demonstrate remarkable technological potential, environmental and sustainability challenges remain significant.

Many high-performance OLED dyes contain heavy metals such as iridium and platinum, creating environmental disposal concerns. Additionally, several fluorescent dyes exhibit photodegradation under prolonged irradiation.

Organic semiconductor systems also face operational instability due to moisture sensitivity and thermal degradation.

Current industrial and academic research is increasingly focused on:

- Metal-free phosphorescent systems
- Biodegradable fluorescent dyes
- Water-processable organic semiconductors
- Recyclable OLED architectures
- AI-assisted molecular engineering
- Nanostructured hybrid dye systems

RESULTS AND KEY FINDINGS

The present analytical investigation identified iridium-complex OLED dyes as the highest-performing systems in terms of electroluminescent efficiency, optical brightness, and display quality.

Cyanine dye systems demonstrated superior multifunctionality and biomedical compatibility because of their combined fluorescence and near-infrared properties.

Leuco dyes continue to exhibit the strongest industrial scalability due to low manufacturing cost and rapid thermal response characteristics.

The study also revealed that future industrial competitiveness will depend not only on optical efficiency but also on environmental sustainability, operational lifetime, and manufacturing feasibility.

Recent literature strongly indicates increasing integration of functional dyes with flexible electronics, wearable diagnostics, smart textiles, and printable electronic systems.

CONCLUSION

The present study demonstrates that functional dyes have evolved into highly advanced multifunctional materials with substantial technological significance in OLED displays, biomedical imaging, organic semiconductors, and intelligent optoelectronic systems. Comparative analysis revealed that iridium-complex OLED dyes and cyanine near-infrared dyes currently represent the most technologically



dominant systems due to their superior optical efficiency and multifunctionality. The study further highlights that future advancements will be strongly influenced by sustainable material engineering, hybrid nanostructures, and AI-assisted molecular optimization. Although photodegradation, operational instability, and heavy-metal toxicity remain major challenges, ongoing developments in organic electronics and nanotechnology are expected to significantly improve the next generation of functional dye systems.

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ENCAPSULATION, GC–MS ANALYSIS AND FUNCTIONAL CHARACTERIZATION OF PIPER BETLE LEAF ESSENTIAL OIL POWDER

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ABSTRACT

Piper betle essential oil is recognized for its bioactive properties; however, its practical application is limited by high volatility, poor aqueous dispersibility, and susceptibility to oxidative degradation. The present study aimed to extract, chemically characterize, and enhance the stability of *Piper betle* essential oil through spray-drying microencapsulation using different wall material systems. Essential oil was extracted by hydro-distillation and analyzed by GC–MS, revealing a sesquiterpene-rich profile dominated by β -caryophyllene, along with bioactive constituents such as eugenol, germacrene D, and α -humulene. Microencapsulation was carried out using sodium caseinate, gum acacia, and maltodextrin, either individually or in combination, to evaluate the influence of wall material composition on encapsulation performance.

Spray-dried powders exhibited low moisture content (3.3–4.5%), high solubility (87–93%), and acceptable flow properties. Encapsulation efficiency ranged from 84.30 to 94.45%, while oil retention ranged from 85.89 to 91.69%, depending on formulation. GC–MS comparison between free oil and encapsulated powder demonstrated substantial preservation of major volatile constituents following spray drying. Among the evaluated formulations, the hybrid system containing sodium caseinate, gum acacia, and maltodextrin showed superior encapsulation efficiency, oil retention, and overall physicochemical stability. Structural and thermal analyses confirmed successful physical entrapment of the essential oil within an amorphous carrier matrix without evidence of chemical degradation.

Overall, the findings indicate that spray-drying microencapsulation using protein–polysaccharide – carbohydrate wall systems is an effective strategy for stabilizing *Piper betle* essential oil and improving its functional applicability, highlighting its potential use as a natural ingredient in food, nutraceutical, and preservative applications.



KEYWORDS

Piper betle; Essential oil; Spray drying; Microencapsulation; GC–MS; Physicochemical properties

INTRODUCTION

In recent years, plant-derived essential oils have gained increasing attention as multifunctional bioactive ingredients, particularly in response to the rising demand for clean-label, natural sourced alternatives in food, nutraceutical, and pharmaceutical products [3,4]. These oils are widely recognized for their antimicrobial, antioxidant, and preservative properties; however, their broader industrial application is frequently constrained by inherent physicochemical instability. Within this context, *Piper betle* L. (betel leaf), a perennial climber belonging to the Piperaceae family, has emerged as a plant of considerable scientific and industrial interest. Widely cultivated across South and Southeast Asia, betel leaf has a long history of use in traditional medicine, and its functional attributes are increasingly validated through modern phytochemical and biological investigations [1–4].

The essential oil extracted from *Piper betle* leaves exhibits a chemically diverse volatile profile composed mainly of terpenoids and phenolic compounds. Previous studies have reported eugenol, chavibetol, estragole, β -caryophyllene, eugenyl acetate, and related mono- and sesquiterpenes as major constituents of the oil [1,2,6]. Although phenolic compounds such as eugenol contribute significantly to antimicrobial and antioxidant activity, sesquiterpene hydrocarbons, particularly β -caryophyllene and humulene, also play an important role in the biological functionality and preservative potential of the oil [3,4]. Owing to this composition, *Piper betle* essential oil has been increasingly proposed as a promising natural ingredient for food preservation, nutraceutical formulations, and functional bioactive systems.

Despite its strong bioactive potential, the direct incorporation of *Piper betle* essential oil into food and industrial formulations remains technologically challenging. Similar to other essential oils, it is highly volatile and susceptible to oxidative degradation, particularly when exposed to heat, light, and oxygen during processing and storage [10,18]. Furthermore, its hydrophobic nature and intense aroma complicate its application in aqueous and semi-solid food matrices, often resulting in poor dispersion, rapid loss of volatile constituents, and undesirable sensory effects [10,18]. These limitations significantly compromise shelf stability, functional consistency, and consumer acceptability, thereby restricting the practical use of the oil in its free form and highlighting the need for effective stabilization strategies.

Microencapsulation has been widely adopted as a practical and effective approach to protect volatile and sensitive bioactive compounds from environmental degradation. By entrapping essential oil droplets within a protective carrier matrix, microencapsulation can reduce volatilization losses, enhance oxidative stability, mask intense aromas, improve handling properties, and facilitate controlled release during application [9–11]. Among the various encapsulation techniques available, spray drying remains one of the most suitable for industrial implementation due to its operational simplicity, scalability, cost-effectiveness, and ability to produce stable, free-flowing powders in a single processing step [9,10].

The efficiency of spray-dried encapsulated systems is strongly influenced by the selection and composition of wall materials. Proteins such as sodium caseinate are commonly employed for their excellent emulsifying properties and ability to stabilize oil–water interfaces, while polysaccharides such as gum acacia contribute to film formation, emulsion stability, and protection against oxidative stress [11–14]. Maltodextrin is frequently incorporated as a matrix-forming agent owing to its favorable drying characteristics, low viscosity at high solid content, good solubility, and neutral sensory profile [10,13]. Recent studies have demonstrated that hybrid wall systems combining proteins and polysaccharides within a carbohydrate matrix can exhibit synergistic interactions, leading to improved encapsulation efficiency, enhanced oil retention, reduced surface oil, and superior physical stability compared to single-component carrier systems [13,14].

Although numerous studies have reported the extraction, chemical composition, and biological activities of *Piper betle* essential oil [1–4,6], systematic investigations integrating chemical profiling with spray-drying microencapsulation and detailed structural characterization remain limited. In particular, comparative studies evaluating the influence of different protein–polysaccharide–carbohydrate wall material combinations on encapsulation efficiency, volatile retention, physicochemical behavior, and thermal stability of *Piper betle* essential oil are scarce. Furthermore, limited information is available regarding the retention of key volatile constituents following exposure to high inlet spray-drying temperatures and their stabilization within amorphous carrier matrices, which is critical for industrial processing and long-term storage [10,13].

In light of these gaps, the present study aimed to develop spray-dried microencapsulated *Piper betle* essential oil powders using different wall material systems based on sodium caseinate, gum acacia, and maltodextrin. The specific objectives were to extract and chemically characterize the essential oil

using GC–MS analysis; evaluate the influence of wall material composition on encapsulation efficiency and oil retention; and investigate the physicochemical, morphological, structural, and thermal properties of the resulting powders using FTIR, XRD, SEM, and DSC techniques. By integrating chemical profiling with comprehensive material characterization, this study seeks to identify an optimized encapsulation system capable of enhancing the stability and functional applicability of *Piper betle* essential oil for potential use in food, nutraceutical, and natural preservative applications.

MATERIALS AND METHODS

Raw Material: Fresh green betel leaves (*Piper betle* L.) were procured from a local market in Chhatrapati Sambhajinagar, Maharashtra, India. Only healthy, mature, and undamaged leaves were selected to ensure uniformity in essential oil yield and chemical composition. The leaves were thoroughly washed with distilled water to remove surface contaminants and shade dried at ambient temperature to eliminate residual moisture. The cleaned leaves were processed immediately for essential oil extraction to minimize volatilization losses and oxidative degradation prior to distillation, as recommended for aromatic plant materials [1,9].

Extraction of Essential Oil: Essential oil extraction was carried out using the hydro-distillation method with a Clevenger-type apparatus (Borosil Glass Works Ltd., India), which is widely employed for laboratory-scale recovery of volatile oils from aromatic plant materials [1,18]. Fresh *Piper betle* leaves were subjected to distillation at 80–90 °C for 2.5–3 h. The distilled oil layer was separated from the aqueous phase and dried over anhydrous sodium sulfate (Merck, India) to remove residual moisture. The oil was transferred to amber glass vials and stored at 4 °C until further analysis. The essential oil yield ranged between 0.50 and 0.90% (v/w) on a fresh weight basis.

GC–MS Analysis of Essential Oil: The chemical composition of the extracted essential oil was analyzed using a gas chromatography–mass spectrometry system (Agilent 7890B GC coupled with Agilent 5977A MSD, USA) equipped with an HP-5MS capillary column (30 m × 0.25 mm × 0.25 µm). Helium was used as the carrier gas at a constant flow rate of 1.0 mL min⁻¹. The oven temperature program was set from 50 °C (held for 2 min) to 250 °C at a rate of 4 °C min⁻¹, with a final hold of 5 min. The injector temperature was maintained at 250 °C, and samples were injected in split mode (split ratio 1:20). Mass spectra were recorded in electron ionization mode at 70 eV with a scan range of 40–500 m/z. Compound identification was performed by comparing retention indices and mass spectra with NIST library databases and published literature data [9,18]. Relative percentage composition was

calculated using peak area normalization. GC–MS analysis was performed for the free essential oil and a representative spray-dried encapsulated sample to evaluate volatile retention after encapsulation.

Preparation of Feed Emulsions: Five feed emulsions (A1, B1, C1, D1, and E1) were prepared to evaluate the influence of wall material composition on encapsulation performance. Sodium caseinate (HiMedia Laboratories, India), gum acacia (Loba Chemie, India), and maltodextrin (DE 10–12, HiMedia Laboratories, India) were selected as wall materials based on their complementary functional properties in emulsion stabilization and matrix formation [11–14].

The wall materials were dissolved in distilled water under magnetic stirring using a hot plate stirrer (Remi Equipment Pvt. Ltd., India) to obtain homogeneous solutions. Essential oil was gradually added to the carrier solution, and Tween 80 (3%, w/w) (Sigma-Aldrich, India) was incorporated as an emulsifier. Emulsification was performed using a high-shear homogenizer (Ultra-Turrax T25, IKA, Germany) operating at 13,000 rpm for 5 min to obtain stable oil-in-water emulsions.

The formulation compositions (dry basis) are presented in Table 1. Table 1. Composition of spray-drying formulations (dry basis, %)

Formulation	Essential oil	Sodium caseinate	Gum acacia	Maltodextrin
	(%)	(%)	(%)	(%)
A1	13.64	13.64	–	72.73
B1	13.04	–	26.09	60.87
C1	13.04	10.87	10.87	65.22
D1	20.83	12.50	–	66.67
E1	20.83	12.50	–	66.67

Formulations A1–C1 had lower oil loading (core-to-wall ratio $\approx$ 1:6.7), whereas D1 and E1 had higher oil loading (core-to-wall ratio $\approx$ 1:3.8). The total soluble solids (TSS) content of emulsions ranged between 21.6 and 23.1 °Brix, measured using a digital refractometer (Atago Co., Japan). Prepared emulsions were immediately subjected to spray drying.

Spray Drying Process: Microencapsulation of Piper betle essential oil was carried out using a laboratory-scale spray dryer (Labultima LU-222 Advanced, India). Spray drying parameters were selected based on previous reports for effective encapsulation of volatile oils [9,10]. The feed emulsions were spray dried at an inlet temperature of 180 °C and outlet temperature of approximately 80 °C, with a feed flow rate of 2 mL min⁻¹ and aspirator air flow rate of 80 m³ h⁻¹. The atomized droplets underwent rapid dehydration, resulting in the formation of dry microcapsules. Powders were collected, sealed in airtight containers, and stored at ambient temperature until further analysis. Powder yield ranged from 23.75 to 27.50%.

Particle Size Distribution and Zeta Potential: The mean particle size, polydispersity index (PDI), and zeta potential of the emulsions were determined using dynamic light scattering (DLS) with a Zetasizer Nano ZS instrument (Malvern Instruments Ltd., UK). Samples were diluted with distilled water prior to measurement to avoid multiple scattering effects. Measurements were conducted at 25 °C, and results were expressed as the average of three independent determinations.

Physicochemical Properties of Encapsulated Powders

- **Moisture Content:** Moisture content was determined gravimetrically by drying samples in a hot air oven (Thermo Scientific, India) at 105 °C until constant weight was achieved [13].
- **Solubility:** Solubility was determined by dispersing powder samples in distilled water followed by centrifugation (Remi Centrifuge, India) and measuring dissolved solids.
- **Bulk and Tapped Density and Flow Properties:** Bulk and tapped densities were measured using a graduated cylinder method with a tapped density tester (Electrolab ETD-1020, India) [13]. Hausner ratio and Carr's compressibility index were calculated to evaluate powder flowability and cohesiveness.

Encapsulation Efficiency

Encapsulation efficiency was determined by quantifying total oil and surface oil content following established procedures for spray-dried essential oil systems [13,19] and calculated as:

$$EE (\%) = \frac{\text{Total oil} - \text{surface oil}}{\text{Surface oil}} \times 100$$

Fourier Transform Infrared (FTIR) Analysis

FTIR spectra of free oil and encapsulated powders were recorded using an FTIR spectrometer (PerkinElmer Spectrum Two, USA) in the range of 4000–400 cm^{-1} to evaluate functional group integrity and possible interactions between essential oil and wall materials [9,23].

X-Ray Diffraction (XRD) Analysis

X-ray diffraction patterns were obtained using an X-ray diffractometer (Bruker D8 Advance, Germany) operated at 40 kV and 30 mA to determine the crystalline or amorphous nature of the encapsulated powders [23].

Scanning Electron Microscopy (SEM)

Surface morphology of spray-dried microcapsules was examined using scanning electron microscopy (JEOL JSM-7610F, Japan) at magnifications ranging from 1000× to 30,000×. Particle shape and surface characteristics were evaluated [13,19].

Differential Scanning Calorimetry (DSC)

Thermal behavior was analyzed using differential scanning calorimetry (DSC 214 Polyma, Netzsch, Germany). Samples were heated from 30 to 300 °C at a rate of 10 °C min⁻¹ under a nitrogen atmosphere to assess thermal transitions and stability of encapsulated systems [13,23].

Statistical Analysis

All experiments were performed in triplicate, and data were expressed as mean ± standard deviation (SD). Statistical analysis was conducted using one-way analysis of variance (ANOVA) followed by Tukey's multiple comparison test at a significance level of $p < 0.05$ using SPSS software (Version 26.0, IBM Corp., USA).

RESULTS AND DISCUSSION

Essential Oil Yield

Hydro-distillation of fresh Piper betle leaves produced an essential oil yield ranging from 0.50 to 0.90% (v/w) on a fresh weight basis. Variations in yield may be attributed to differences in leaf maturity, inherent moisture content, and natural chemotypic variability of the plant material. The extracted oil was pale yellow with a characteristic aromatic odor, indicating efficient recovery of volatile constituents without observable thermal degradation.

The yield values obtained in the present study fall within the range reported in previous investigations for Piper betle essential oil extracted by hydro-distillation [1,18], confirming the suitability of the extraction conditions. Adequate oil recovery ensured sufficient availability of bioactive compounds for subsequent encapsulation and physicochemical characterization studies.

GC–MS Characterization of Free Essential Oil and Encapsulated Powder

The chemical composition of Piper betle essential oil before and after encapsulation was analyzed using GC–MS, and the identified volatile compounds are presented in Table 2. The essential oil exhibited a phenolic-rich profile dominated by allyl pyrocatechol and eugenol, along with other bioactive constituents such as chavicol, hydroxychavicol, caryophyllene, germacrene D, and α -humulene. These compounds are widely associated with the antimicrobial and antioxidant properties of betel leaf essential oil [3,4].

Encapsulation resulted in partial reduction of volatile compound concentrations; however, substantial retention of key bioactive constituents was observed. The retention of major compounds ranged from 76.3 to 84.8%, indicating effective protection of volatile components during the spray-drying process.

Table 2. Chemical composition of Piper betle essential oil before and after encapsulation

Compound	Retention time	Free oil	Encapsulated powder	Retention
	(min)	(%)	(%)	(%)
Allyl pyrocatechol	14.82	38.46	32.15	83.6
Eugenol	12.37	21.28	18.04	84.8
Chavicol	10.94	12.64	10.11	80.0
Hydroxychavicol	15.63	9.87	8.02	81.3
Caryophyllene	18.91	6.45	5.09	78.9
Germacrene D	20.34	3.12	2.38	76.3
α -Humulene	19.44	2.05	1.57	76.6
Other compounds*	minor —	6.13	3.64	—

Notes: Identification was performed using NIST library comparison. Retention (%) was calculated as the ratio of compound peak area in encapsulated powder to that in free oil.

Retention of Volatile Compounds after Spray Drying

The retention behavior of volatile compounds after spray drying demonstrated that phenolic constituents such as eugenol and allyl pyrocatechol exhibited higher stability compared to sesquiterpenes. The relatively higher retention of phenolic compounds may be attributed to stronger interactions between aromatic functional groups and the carrier matrix, which reduce volatilization losses during thermal processing.

Despite exposure to a high inlet temperature (180 °C), the substantial preservation of bioactive constituents suggests rapid formation of a protective matrix during drying, limiting evaporation and oxidative degradation. Similar retention trends have been reported for encapsulated essential oil systems using protein–polysaccharide wall materials [9,10], confirming the effectiveness of spray drying as a stabilization technique.

Particle Size, Zeta Potential, and Physicochemical Properties

The particle size distribution, zeta potential, and physicochemical properties of the spray-dried formulations are presented in Table 3. Significant differences among formulations were observed ($p < 0.05$), indicating the influence of wall material composition and oil loading on encapsulation behavior.

Particle size ranged from 289 to 412 nm, with formulation E1 showing the smallest particle size and lowest polydispersity index, indicating improved emulsion stability. Zeta potential values ranged from -21.4 to -32.6 mV, suggesting moderate electrostatic stability of the emulsions. Higher negative zeta potential observed in formulations with higher gum acacia content may be associated with increased surface charge density, improving colloidal stability.

Moisture content decreased progressively from A1 to E1, indicating improved drying efficiency at higher carrier ratios. Solubility values ranged from 71.3 to 85.7%, with higher solubility observed in formulations containing greater maltodextrin content due to enhanced hydrophilicity.

Encapsulation efficiency increased from 68.2 to 86.5%, demonstrating improved oil entrapment with optimized wall material composition and higher solid content.

Table 3. Physicochemical characteristics and encapsulation efficiency of spray-dried formulations

Parameter	A1	B1	C1	D1	E1
Mean particle size (nm)	412 ± 18	368 ± 15	325 ± 12	301 ± 10	289 ± 9
Polydispersity index	0.42	0.39	0.36	0.33	0.31
Zeta potential (mV)	-21.4	-24.7	-27.9	-30.2	-32.6
Moisture content (%)	5.84	5.21	4.73	4.35	4.11
Solubility (%)	71.3	75.6	78.9	82.4	85.7
Encapsulation efficiency (%)	68.2	73.9	79.6	83.8	86.5

FTIR Analysis

FTIR spectra of free essential oil exhibited characteristic absorption bands corresponding to phenolic -OH stretching and aromatic functional groups. These characteristic bands were retained in the spectra of encapsulated powders with minor intensity variations, indicating physical entrapment of the oil without chemical degradation.

X-Ray Diffraction Analysis

XRD patterns of encapsulated powders displayed broad halos without sharp crystalline peaks, confirming the amorphous nature of the carrier matrix and uniform dispersion of essential oil within the encapsulating materials.

Morphological Characteristics (SEM)

SEM micrographs revealed predominantly spherical microcapsules with smooth to slightly wrinkled surfaces, characteristic of spray-dried powders. The absence of cracks or visible oil leakage confirmed effective encapsulation and structural integrity.

Thermal Properties (DSC)

Thermal analysis results are presented in Table 4. Encapsulated formulations exhibited significantly higher glass transition temperatures (T_g) and endothermic peak temperatures compared to free essential oil, indicating improved thermal stability following encapsulation. The increase in enthalpy values further suggests stronger interactions between essential oil and wall materials.

Table 4. Thermal properties of free essential oil and encapsulated formulations

Sample	T_g (°C)	Endothermic peak (°C)	ΔH (J/g)
Free essential oil	—	52.4	18.6
A1	68.7	96.2	41.3
B1	71.9	101.4	44.8
C1	75.6	108.9	49.5
D1	79.8	113.6	52.7
E1	82.3	118.1	56.4

OVERALL DISCUSSION

Overall, the results demonstrate that spray-drying microencapsulation effectively stabilized *Piper betle* essential oil while retaining a substantial proportion of its key bioactive constituents. Formulations with optimized wall material composition exhibited improved physicochemical stability, higher encapsulation efficiency, and enhanced thermal resistance, highlighting the importance of carrier system selection in developing stable essential oil powders.

CONCLUSION

The present study successfully demonstrated the extraction, chemical characterization, and spray-drying microencapsulation of *Piper betle* essential oil using different wall material systems. Hydro-distillation produced essential oil yields within the expected range, and GC–MS analysis confirmed a phenolic-rich chemical profile dominated by allyl pyrocatechol and eugenol, along with sesquiterpenes such as caryophyllene, germacrene D, and α -humulene, which contribute significantly to the oil's functional bioactivity.

Spray-drying encapsulation effectively stabilized the essential oil, resulting in powders with controlled particle size distribution, moderate electrostatic stability, reduced moisture content, and improved aqueous solubility. Encapsulation efficiency increased progressively with optimized wall material



composition, indicating improved oil entrapment and protection against volatilization losses. The retention behavior of volatile compounds demonstrated that phenolic constituents exhibited greater stability during spray drying compared to more volatile components, confirming the protective role of the carrier matrix under high-temperature processing conditions.

Thermal analysis further revealed a significant increase in glass transition temperature and endothermic peak values in encapsulated formulations compared with free essential oil, indicating enhanced thermal stability due to interactions between the oil and wall materials. Structural characterization confirmed successful physical incorporation of the essential oil into an amorphous carrier matrix without evidence of chemical degradation.

Overall, this study provides a comprehensive experimental framework integrating chemical profiling, spray-drying microencapsulation, and physicochemical characterization of Piper betle essential oil. The findings highlight the potential application of spray-dried encapsulated betel leaf essential oil as a stable natural ingredient for food, nutraceutical, and preservative applications. Future research should focus on storage stability, controlled release behavior, and biological efficacy of encapsulated systems in real food matrices to further validate their industrial applicability.

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FORMULATION AND EVALUTION OF HEARBAL TOOTH POWDER

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ABSTRACT

Tooth powders consisting of various ingredients that are available in the market in a wide range. Hence modern methods focusing on these aspects are useful for the standardization of herbs and their formulations. Consumers believed by using herbal-based toothpowders are safe, effective, and less toxic. This study is thus aimed to provide an alternative to the consumer and formulate herbal tooth powder using Clove, Neem Stem, Acacia Stem, Stevia Leaf, Mustard Oil, Salt, Ginger and Amla. The oral cavity infections are the most common types of infections. Dental caries is an infectious disease, causes damage and infection of enamel and dentine.

If it is not treated, the infection continues and will lead to tooth loss. The mouth contains normal flora of opportunistic bacteria that are normally non-pathogenic. The imbalance of this situation causes infection and tooth decay. Streptococcus mutants are considered as the main species involved in the development of dental caries. S. mutants, acid-producing bacteria, causes fermentation of carbohydrates which results in tooth decay. Therefore, in the present work, the following aspects of Herbal tooth powders were planned for the formulation, standardization of herbal tooth powder, and anti-bacterial screening of the extracts of herbal tooth powder.

KEYWORDS

Triphala Powder, Arjuna Bark Powder, Trituration

INTRODUCTION

Ayurveda recommends using fresh plant twigs for cleaning the teeth. However, it is not possible for everyone to collect fresh twigs of recommended plants on a daily basis. So, ayurveda also provide a solution for it. In this article, we will discuss how to make herbal tooth powder at home for children and adults. Then learn how to use this ayurvedic herbal tooth powder and what are its benefits. This tooth powder is the most effective remedy for prevention and treatment of health problems related to gums



and teeth. Tooth powder is a mixture of a variety of ingredients that acts as an alternative to toothpaste as a cleaning agent. The main ingredients include baking soda, herbs like cloves, mint or cinnamon, and artificial sweetener for taste.

Dental powders are made with all-natural and often organic ingredients, and they are free from potentially harmful chemicals, including artificial flavors and colors. When it comes to overall effectiveness, studies that have shown that tooth powder may actually be better at reducing plaque than regular toothpaste. Tooth powder is an alternative to toothpaste. It comes in both a fluoride and non-fluoride version. Tooth powder was generally used among the Romans, who used a variety of substances, such as the bones, hoofs, and horns of certain animals; crabs, egg-shells, and the shells of the oyster and the murex.

The formation of small dental cavities can be reversed by a process called remineralization, when the deposition of minerals is applied to damaged areas of a tooth. Fluoride works by helping to remineralize your teeth in two ways, internally and externally. Herbal tooth powder is infused with potent Ayurvedic herbs that possess healing and curative powers. It effectively contributes to a healthy smile and fresh breath, besides doing wonders for your gums and teeth. Wild clove extracts are a key component in our tooth powder and help in reducing sensitivity. Tooth powder is thought to have originated many thousands of years ago. Ancient people may have used ingredients such as myrrh, burnt eggshells, crushed animal bone ash, and oyster shells to create powders able to remove mouth odor, plus clean and polish teeth.

METHODOLOGY

Ensure you have Triphala fruits (Amla, Bahera, Harad), Khadira bark, and Arjuna bark. Also, prepare Trikatu powder, which includes common kitchen spices like black pepper, long pepper, and ginger powder. All ingredients should be in equal quantities. Take the Triphala fruits, Khadira bark, and Arjuna bark and wash them thoroughly under running water to remove any dirt or impurities.

Dry the washed ingredients properly by spreading them out in sunlight. Allow them to dry completely. Note that cardamom, dalchini (cinnamon), clove, and the ingredients of Trikatu powder should not be washed. These ingredients contain aromatic compounds that can evaporate during the drying process, reducing their potency and flavor.

For cardamom, dalchini, clove, and Trikatu powder, if there is any dust, you can use a blower to gently remove it. Otherwise, assume they are clean and pure. Once the Triphala fruits, Khadira bark, and



Arjuna bark are completely dry, grind each ingredient separately into a fine powder. Measure each of the powdered ingredients, including the Trikatu powder, according to the quantity mentioned in the above table (which is not visible in the image).

Mix all the powdered ingredients together thoroughly in the specified quantities to ensure a homogenous blend. Transfer the final mixture and store it in an airtight glass or food-grade plastic container to maintain its freshness and potency.

LITERATURE REVIEW

Kudale et al. (2024)

Authors: Sakshi Kisan Kudale, Sakshi Sunil Dhavan, Supriya Ajit Davkare, Bhaskar Namdev Bangar

Title: Formulation and Evaluation of Herbal Tooth Powder using *Azadirachta indica*, *Eugenia caryophyllus* and other: A Review

The authors reviewed herbal tooth powder formulations containing Neem (*Azadirachta indica*), Clove (*Eugenia caryophyllus*), and medicinal herbs. The study concluded herbal tooth powders possess antimicrobial activity and may help reduce plaque, gingivitis, and periodontal disorders.

Mhavan et al. (2025)

Authors: Shravani Satish Mhavan, Kunal R. Hake, Nitin Gawai, Vaishnavi R. Talekar

Title: Formulation and Evaluation of Herbal Tooth Powder: A Systematic Review The review summarized recent herbal tooth powder formulations and evaluation methods. Neem, Clove, and Licorice were highlighted as major ingredients due to antimicrobial and anti-inflammatory activities. The authors suggested herbal tooth powders can serve as alternatives to synthetic oral care products.

Patel et al. (2024)

Authors: Yash Patel, Twinkal Patel, Sanjana Patel, Shilpa Patel, Nikunj Patadiya Title: Preparation and Evaluation of Herbal Tooth Powder Using Herbal Resources

The researchers evaluated physicochemical properties and safety parameters of herbal tooth powder. The formulation showed acceptable pH, moisture content, and stability with no irritation observed during safety testing. Further clinical studies were recommended. *Pharmacognosy Journal*

Anwar et al. (2025)

Authors: M.A. Anwar, G.A. Sayed, D.M. Hal et al.

Title: Herbal Remedies for Oral and Dental Health: A Comprehensive Review The review reported that herbal ingredients possess antimicrobial, antioxidant, anti-inflammatory, and anticaries activities beneficial for oral health. Herbal products may help manage gingivitis, oral pathogens, and periodontal disease.



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COMPONENTS

Biological Name: BIBHITAKI, HARITAKI, AMALAKI (AMLA)

Triphala (Sanskrit; tri=three and phala = fruits) is a well-recognized and revered Polyherbal medicine consisting of dried fruits of the three plant species *Emblica officinalis* (Family Euphorbiaceae), *Terminalia bellerica* (Family Combretaceae). And *Terminalia chebula* (Family Combretaceae) that are native to the Indian subcontinent [1]

The aim of this article is to review the current literature on the therapeutic uses and efficacy of triphala. Herbal remedies are among the most ancient medicines used in traditional systems of Healthcare such as Ayurveda. Triphala, a well-recognized and highly efficacious polyherbal Ayurvedic medicine consisting of fruits of the plant species *Emblica officinalis* (Amalaki), *Terminalia bellerica* (Bibhitaki), and *Terminalia chebula* (Haritaki), is a cornerstone of Gastrointestinal and rejuvenative treatment.[2]

A Sanskrit word meaning the knowledge of life or the science of perfect health, is the traditional System of personalized medicine from

India, which emphasizes disease prevention and health Promotion.[3]

Oral rinses made from these are used in periodontal therapy. Triphala is one of these with wide Spectrum of activity. According to the Sushruta Samhita, Triphala can be used as a gargling Agent in dental diseases [4]

Synonyms: Triphala Churna, Three Fruit Powder, Ayurvedic Digestive Powder

Biological Source

Triphala Powder is prepared from the dried fruits of: *Terminalia chebula*, *Terminalia bellerica*, *Phyllanthus emblica*

Geographical Source

The plants are mainly found in: India, Nepal, Sri Lanka, Bangladesh

In India, they are commonly cultivated in:

Maharashtra, Kerala, Tamil Nadu, Madhya Pradesh, Himalayan regions

Chemical Constituents

Tannins, Gallic acid, Ellagic acid, Chebulinic acid, Vitamin C, Flavonoids, Polyphenols

Physical Characteristics



Color: Brown to dark brown, Odor: Characteristic herbal odor, Taste: Sour, bitter, astringent, and slightly sweet, Form: Fine powder

Medicinal Uses

Improves digestion and metabolism, Acts as a mild laxative, Helps detoxify the body, Boosts immunity, supports eye and skin health, Helps manage constipation

KHADIRA (CATECHU) BARK POWDER:

Biological Name: ACACIA

Catchu is an extract of acacia trees used variously as a food additive, astringent, tannin, and dye. It is extracted from several species of Acacia, but especially *Senegalia catechu* (*Acacia catechu*), by boiling the wood in water and evaporating the resulting brew. It is also known as cutch, black cutch, cachou, cashoo, terra Japonica, or Japan earth, and also katha in Hindi, kaath in Marathi, khaira in Odia, khoyer in Assamese and Bengali, and kachu in Malay. Benefits & Features Khadira Powder promotes the production of new skin cells for healthy and natural skin glow and complexion. The bitter taste and astringent properties of this Ayurvedic supplement promote regular cleansing of the blood and body fluids and thereby boosting immunity. It helps in weight management when accompanied by regular physical exercise and a balanced diet. It stimulates the regular absorption of nutrients for digestive and cellular comfort. This Ayurvedic supplement also supports natural blood purification and skin rejuvenation by providing healthy toxin removal support.[5]

ARJUNA BARK POWDER:

Biological Name: TERMINALIA ARJUNA

Terminalia arjuna is a tree of the genus *Terminalia*. It is commonly known as arjuna or arjun tree in English. The arjuna is seen across the Indian Subcontinent, and usually found growing on river banks or near dry river beds in Uttar Pradesh, Bihar, Maharashtra, Madhya Pradesh, West Bengal, Odisha and south and central India, along with Sri Lanka and Bangladesh.[6] It has also been planted in Malaysia, Indonesia and Kenya. Arjuna bark powder protects the heart due to its cardioprotective property. It helps in the proper functioning of the heart by strengthening the heart muscles.[7] It also has anti-hypertensive property that helps reduce the levels of high blood pressure. Arjuna is a well-known herb that helps manage heart functions.[8]

DALCHINI (CINNAMON):

Biological Name: TRUE CINNAMON TREE



Cinnamon is a spice obtained from the inner bark of several tree species from the genus *Cinnamomum*. Cinnamon is used mainly as an aromatic condiment and flavouring additive in a wide variety of cuisines, sweet and savoury dishes, Cinnamon is a spice that is made from the inner bark of trees scientifically known as *Cinnamomum*. It helps your body fight infections and repair tissue damage. However, inflammation can become a problem when it's chronic and directed against your body's own tissues. Cinnamon may be useful in this regard.

Studies show that this spice and its antioxidants have potent anti-inflammatory properties.[9] Cinnamon is well known for its blood-sugar-lowering properties. Apart from the beneficial effects on insulin resistance, cinnamon can lower blood sugar by several other mechanisms. Cinnamon has been widely studied for its potential use in cancer prevention and treatment. Overall, the evidence is limited to test-tube and animal studies, which suggest that cinnamon extracts may protect against cancer.[10]

GREEN CARDAMOM POWDER:

Biological Name: TRUE CARDAMOM

Cardamon or cardamum is a spice made from the seeds of several plants in the genera *Elettaria* and *Amomum* in the family *Zingiberaceae*. Both genera are native to the Indian subcontinent and Indonesia. They are recognized by their small seed pods: triangular in cross section and spindle-shaped, with a thin, papery outer shell and small, black seeds; *Elettaria* pods are light green and smaller, while *Amomum* pods are larger and dark brown.[11] The word "cardamom" is derived from the Latin *cardamōmum*, which is the Latinisation of the Greek *Καρδάμουρον* (*kardamomam* compound of *κάρδον* (*kárdamon*, "cress") and *αουον* (*ámōmon*), which was probably the name for a kind of Indian space plant.

It may lower blood pressure, improve breathing and aid weight loss. What's more, animal and Test-tube studies show that cardamom may help fight tumors, improve anxiety, fight bacteria and protect your liver, though the evidence in these cases is less strong. The green pods, *elettaria cardamomum*, also known as "true cardamom," have the characteristics most recognized as cardamom flavor: an herbal warmth like a fragrant cross between eucalyptus, mint, and pepper—more citrusy than fennel and sweeter than cumin.[12]

CLOVE POWDER:

Biological Name: SYZYGIUM AROMATICUM:

Clove, (*Syzygium aromaticum*). Tropical evergreen tree of the family *Myrtaceae* and its Small reddish brown flower buds used as a spice. Cloves were important in the earliest spice trade and are believed to be indigenous to the Moluccas, or Spice Islands, of Indonesia. Cloves are the aromatic



flower buds of a tree in the family Myrtaceae, *Syzygium aromaticum*. They are native to the Maluku Islands (or Moluccas) in Indonesia, and are commonly used as a spice, flavoring or fragrance in consumer products, such as toothpaste, soaps, or Cosmetics.

Cloves are available throughout the year owing to different harvest seasons across various countries.[13] Clove develops on the sloping plots of the Nilgiris, Kanyakumari, Nagercoil, Tirunelveli locale of Tamilnadu, South Kanara region of Karnataka, and Kollam, Kottayam, Kozhikode, and Thiruvananthapuram regions of Kerala. Clove oil contains the active ingredient eugenol, which is a natural anesthetic.

It helps numb and reduce pain to ease a toothache. Eugenol also has natural anti-inflammatory properties. It May reduce swelling and irritation in the affected area.[14]

SENDHA NAMAK (ROCK SALT):

Biological Name: SODIUM CHLORIDE:

Sendha namak, a type of salt, is formed when salt water from a sea or lake evaporates and leaves behind colorful crystals of sodium chloride. It's also called halite, saindhava lavana, or rock salt. Himalayan pink salt is one of the best known types of rock salt, but several other varieties exist. Rock salt is an effective digestive agent that can soothe gastritis and prevent bloating. A Popular remedy for issues related to the stomach, it is a natural solution for acidity and Heartburn. Rock salt has major cosmetic value as a teeth whitener.

In order to give this a shot, brush your teeth with the Ayush Whitening Rock Salt Toothpaste. Crafted in association with the Arya Vaidya Pharmacy (AVP). This toothpaste combines rock salt and Arimedasa Tailam, an Ayurvedic oil blend of 40 herbs, which work together to make your teeth stronger, whiter and rid them of stubborn coffee stains.

EVALUATION:

Trituration Method (Pharmaceutical: Processes) A trituration is a mixture of one or more finely ground powdered drugs. The trituration is a mix of a finely ground drug and lactose. A trituration was formed by mixing ground sodium chlorite and potassium chloride salts.

SR. NO	INGREDIENTS	CATEGORY	QUANTITY
1	Triphala Powder	Antibacterial	12.5 Gm
2	Khadira (Catechu) Bark Powder	Antibacterial	12.5 Gm
3	Arjuna Bark Powder	Antiseptic	7.5 GM
4	Dalchini (Cinnamon)	Antiseptic	7.5 GM
5	Greencardamom Powder	Prevent Bad Breath	7.5 GM
6	Clove Powder	Antibacterial	2.5 Gm
7	Sendha Namak (Rock Salt)	Antiseptic	2.5 Gm

FORMULATION:

EVALUATION TEST:

Weight of Powder = 50 GM Bulk density = Weight of powder/volume of powder = $50/60 = 0.83$ Tap

Density = Weight of powder/min.volume occupied after tapping = $50/43 = 1.16$

Angle of Repose(θ) = $\tan^{-1} h/r = 44.12$

Result:

The herbal tooth powder was successfully prepared using natural ingredients such as neem powder, clove powder, mint powder, turmeric, and salt. The prepared tooth powder showed good appearance, pleasant smell, and fine texture.

CONCLUSION

Herbal tooth powder helps maintain oral hygiene by reducing plaque, bad breath, and bacterial growth. Neem and clove possess antimicrobial properties, while mint provides freshness. Turmeric contributes anti-inflammatory action, and salt supports cleaning action.

The prepared formulation showed acceptable physical properties and demonstrated potential effectiveness in maintaining dental health. Herbal tooth powder may serve as a natural alternative to chemical-based oral care products with fewer side effects. Overall, the study indicates that herbal tooth powder is safe, economical, and useful for daily oral care.



Note: If you suffer from pyorrhea or any gum or dental problems, then mix this powder in mustard oil instead of water or honey. Using this herbal tooth powder in this way, you will get rid of pyorrhea, bleeding gums, tooth pain, and other dental and gum problems.

CONCLUSION

This research endeavors to scientifically validate the efficacy of a novel herbaltooth powder formulation, rooted in Ayurvedic principles, for comprehensive dental care. By meticulously selecting eight potent natural ingredients – Triphala, Catechu bark, Arjuna bark, Cinnamon, Green Cardamom, Clove, Trikatu, and Sendha Namak – the formulation aims to address multiple facets of oral hygiene. The anticipated outcomes ofthe [Specify methodology, e.g., in vitro and/or clinical study] will provide valuable insights into the formulation's potential to control plaque, promote gingival health through its antimicrobial, anti-inflammatory, and astringent properties, and freshen breath. The primary outcome measures, including [Specify outcome measures], will allow for a quantitative assessment ofthe herbal tooth powder's effectiveness, potentially in comparison to [Specify comparator if applicable].

The central hypothesis posits that this unique blend of traditional herbs and spices will demonstrate significant improvements in key oral hygiene parameters. Ultimately, the findings ofthis investigation are expected to contribute meaningfully to the growing scientific evidence supporting the use of herbalremedies in maintaining optimal dental health, offering a natural and potentially effective alternative for daily oral hygiene practices. The successful validation of this herbal tooth powder could pave the way forits integration into broader oral care regimens, promoting both efficacy and a holistic approach to dental well-being.

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PATHOLOGICAL CHANGES IN FRESHWATER FISH CHANNA STRAITUS (LECEPEDE, 1800) DUE TO NEMATODE INFECTION FROM KAIGAON TOKA (MS) INDIA

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ABSTRACT

The freshwater spiny eel, *Channa straitus* (Lecepede, 1800), is a commercially important fish species that frequently harbors a variety of helminth parasites. Among these, nematodes of the genus *Procamallanus* are known to cause significant tissue damage. This study was conducted to evaluate the histopathological impact of nematode infection on the visceral organs, primarily the liver and intestine, of *C. straitus*. Histopathological analysis revealed severe structural changes in the infected organs. In the intestine, there was a marked destruction of the mucosal epithelium, shortening of the villi, and infiltration of inflammatory cells in the submucosa. These pathological changes likely interfere with the metabolic and digestive functions of the host, potentially reducing its growth, immunity, and overall market value.

KEYWORDS

Channa straitus, Histopathology, *Procamallanus*

INTRODUCTION

The genus *Channa*, popularly known as snakeheads, constitutes a critical component of India's freshwater biodiversity and is widely distributed across the Indo-Gangetic plains and the Western Ghats (Shanchita et al., 2015). These air-breathing teleosts are highly valued in the Indian subcontinent not only as a primary protein source but also for their therapeutic role in traditional medicine, where they are utilized for tissue repair and post-operative recovery (Verma et al., 2018). Despite their physiological resilience, *Channa* populations in India are increasingly threatened by parasitic infestations, which act as a major biological bottleneck in aquaculture (Bhure et al., 2016). Recent studies in various Indian states indicate that environmental stressors significantly influence the prevalence and intensity of these pathogens, necessitating urgent research into their histopathological effects to ensure the sustainability of freshwater fisheries (Khalil et al., 2014). As a carnivorous



predator, its diet primarily consists of aquatic insects, crustaceans, and small forage fish, a feeding habit that directly facilitates its role as a definitive host for various helminth parasites (Nurliza et al., 2022). The transmission of nematodes often occurs through the ingestion of infected intermediate hosts, such as copepods or small mollusks, which are abundant in the eel's natural habitat (Hiware, 2015).

In the context of parasitology, *C. straitus* is frequently used as a biological model to study the impact of helminthiasis on wild fish populations. Furthermore, the seasonal prevalence of these infections is often linked to environmental factors such as water temperature and monsoon cycles, which influence both the availability of intermediate hosts and the immunity of the fish (Wankhede, 2004). Understanding these ecological and physiological dynamics is essential for maintaining the health of inland fisheries, where *C. straitus* remains a commercially significant food source.

The parasitic fauna of *Channa straitus* is remarkably diverse, consisting of a complex assemblage of cestodes, nematodes, and trematodes that occupy distinct ecological niches within the host. Cestodes, particularly from the genera *Senga* and *Circumoncobothrium*, are frequently the most dominant parasites observed in this species, often found firmly anchored to the intestinal wall via specialized hooks and suckers (Padwi et al., 2024). In addition to the previously discussed nematodes, trematode infections such as those by *Allocreadium* further contribute to the host's pathological burden by invading the liver and air bladder, where they induce significant inflammatory infiltration and tissue degeneration (Dhole et al., 2010). The co-occurrence of these varied helminth groups leads to a synergistic impact on the fish's physiology, resulting in impaired nutrient absorption, reduced reproductive success, and a general decline in the host's immune competence.

Understanding the pathological relationship between nematodes and *C. straitus* is crucial, as these infections can impair nutrient absorption and suppress the host's immune system. The present investigation is done by studying the histopathology of freshwater fish *C. straitus* from Kaigaon toka infected with Nematode *Procamallanus*.

MATERIAL AND METHODS

Study Area and Site Selection: The research was conducted at Kaigaon Toka (19° 37' 38" N, 75° 01' 46" E), located in the Gangapur Tehsil of Chhatrapati Sambhajnagar (formerly Aurangabad) district, Maharashtra, India. This site is ecologically unique as it represents the confluence of the Godavari and



Pravara rivers. The area is characterized by a tropical semi-arid climate with distinct seasonal fluctuations that influence the river's flow and the prevalence of aquatic parasites.

Collection and Transport of Specimens: Host specimens of the spiny eel, *Channa straitus*, were collected periodically from the riverbank in the year 2022-23 at Kaigaon Toka with the assistance of local fishermen using cast nets and gill nets. Freshly caught fish were immediately placed in plastic containers with river water and transported to the laboratory for parasitological examination.

Parasitological Examination: In the laboratory, the fish were pithed and measured for total length and weight. The body cavity was opened via a longitudinal incision to expose the visceral organs. The gastrointestinal tract, liver, and stomach were removed and placed in separate Petri dishes containing 0.7% physiological saline solution. These organs were carefully examined under a stereomicroscope to detect the presence of nematodes.

Parasite Fixation and Identification: Recovered nematodes were gently detached from the host tissue using fine needles. They were washed in saline, fixed in 4% formalin or hot 70% alcohol, and cleared in lactophenol for morphological study. Identification was carried out using standard keys provided by Yamaguti (1961) and other relevant taxonomical literature.

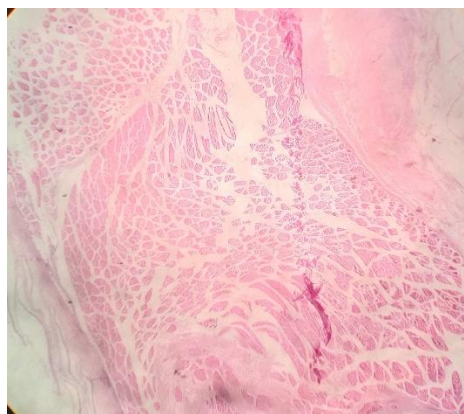
Histopathological Techniques: For the histopathological study, small pieces (approx. 5 mm) of infected tissues (intestine, liver, or stomach) were excised along with the attached or encysted parasites. Fixation: Tissues were fixed in Bouin's fluid for 24 hours to preserve cellular architecture. Processing: The fixed samples were washed in running tap water, dehydrated through a graded series of alcohol (30% to 100%), and cleared in xylene. Embedding: Tissues were embedded in paraffin wax (melting point 58–60°C) to form blocks. Sectioning: Thin sections of 6–8 µm thickness were cut using a rotary microtome.

Staining: The sections were stained using the Haematoxylin and Eosin (H&E) double-staining technique. The best slides were selected, observed under a light microscope, and photomicrographs were captured to document tissue alterations such as necrosis, inflammatory infiltration, and mucosal damage.

RESULTS AND DISCUSSION

The investigation conducted at the Kaigaon Toka research site revealed that *Channa straitus* is subject to significant physiological stress due to nematode infestation, with the highest parasite

prevalence and intensity recorded during the summer season. Morphological identification confirmed that the gastrointestinal tract was primarily colonized by



A) Showing Normal Intestinal Tissue



B) Showing Infected Intestinal Tissue

nematodes of the genus *Procamallanus*, which were found deeply embedded in the host tissues. Histopathological examination of the infected organs showed a clear transition from localized mechanical injury to systemic tissue degradation. In the intestine, the results demonstrated the total destruction of the mucosal epithelium and the blunting of villi, effectively reducing the surface area available for nutrient absorption. Furthermore, the intestinal submucosa exhibited heavy infiltration of inflammatory cells, signaling a robust but costly immune response by the host.

The histopathological findings in the present study confirm that nematode infections cause substantial structural and functional impairment in *Channa straitus*. The observed destruction of the intestinal mucosal epithelium and the blunting of villi are consistent with the "mechanical damage hypothesis" proposed by Dhole et al. (2010), who argued that the attachment of nematodes like *Camallanus* leads to localized necrosis and reduces the host's nutrient



absorption capacity. The severe inflammatory infiltration of eosinophils and lymphocytes in the submucosa reflects a chronic cellular immune response, which is a hallmark of helminthiasis in freshwater teleosts (Hiware, 2015).

At the Kaigaon Toka site, the confluence of the Godavari and Pravara rivers provides a unique ecological niche where the abundance of intermediate hosts, such as copepods, likely drives the high prevalence of infection. The seasonal peak observed during the summer months aligns with the research of Wankhede (2004), who noted that higher water temperatures in the Marathwada region accelerate the life cycles of both the parasites and their vectors. This increased "parasitic load" during the summer leads to the systemic pathology observed in the liver, including the rupture of hepatic sinusoids and focal necrosis. Such hepatic damage is particularly detrimental, as the liver is the primary organ for detoxification and metabolic regulation in fish (Kadam *et al.*, 2011). Furthermore, the formation of fibrous capsules around encysted larvae suggests a host-parasite "evolutionary tug-of-war." While the fish attempts to sequester the parasite to prevent further organ penetration, the presence of these cysts alone can cause pressure atrophy in adjacent healthy tissues. These results are in agreement with Pawar (2011), who suggested that chronic helminth infections in *C. straitus* are a significant factor in the decline of fish health and marketability in the Godavari river basin. Ultimately, the cumulative histopathological alterations observed at Kaigaon Toka indicate that nematode parasites are not merely "passengers" but active pathogens that significantly threaten the ecological

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HUMAN RIGHTS AND ITS IMPLICATIONS: A STUDY IN INDIAN CONTEXT

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ABSTRACT

The concept of Human Rights is not new to India. It is inherent part of socio, economic and cultural life of Indian society. A number of religious, literary, social and philosophical texts from ancient to modern times advocated the concept based on 'Duty', in contrast to that of the Western culture of Rights. After independence, the framers of constitution, taking into consideration of both Eastern and Western philosophies, have developed Human Rights concept to suit according to the needs of Indian polity.

KEYWORDS

Human Rights and Indian perspective, Post-independence Constitution, Indian Polity, Civil Rights, Violation and guarantee

INTRODUCTION

International Law of human rights primarily imposes obligations upon nation-states to implement the standards of it to alleviate the intensity of conflicts and to establish peace and security. These objectives of international law and as well that of human rights could be achieved only through the dissemination and promotion in national sphere by States. To fulfill the mandate without restoring to theoretical perplexities, nation-states around the world incorporated the tenets of international law of human rights to implement the mandate through their respective constitutional and legal texts for absorption and promotion.

The framers of Constitution under the leadership of Dr. Babasaheb Ambedkar designed the legal tenets of human rights philosophy with a blend of international and indigenous philosophical reflections of India, based on Justice, Liberty and Equality to establish a duty bound fraternity to realise their rights as guaranteed by law. This fine blend of philosophical mixture of eastern and western ideological tenets through fundamental rights, directive principles of state policy have been further expanded by the judiciary through the legal acumen to assist the populace of the polity to realise their dreams of cherished values of equality, freedom, life and liberty. However, economic, socio, political, cultural imbalances that prevail in the country for long upset the applecart to bloom the rights of people, the way in which they are advocated to take pleasure in their enjoyment.



In order to restore the original legal position and to extend a helping hand to the needy, a number of welfare measures are advocated by the state on a continuous basis. Further, to achieve the objectives apart from the state, advocacy groups, people of all sections need to take active part for the further promotion of Human Rights to wipe out tears from every eye. With this inspiration, this book discusses subtly human rights in the Indian Context with a remedial mechanism to address the problems.

Indian Bill of Rights:

The legal and other texts of ancient and medieval India advocated duty as the prime concept for augmentation of rights of the individual through the legal tenet of 'Dharma'. However, the arrival of foreign rulers and their divide and rule policy brought in disastrous results for the promotion and protection of individual rights in the modern period.

To resist the policies of colonial masters and to drive them from the country. Indian National Congress' was established in 1885. A number of movements have been initiated under its banner to release the people from the bondage of colonial rule and to restore the rights of people at every level. Among the various movements, the Purna Swaraj and the Home Rule Movement richly contributed for the development of Indian Bill of Rights. In this regard, the report prepared by Mr. Motilal Nehru in 1928 enumerated certain rights that were to be conferred upon the Indian subjects by British colonial Masters. The rights that were enumerated in the report of Nehru are popularly referred to as 'Indian Bill of Rights'. In a way, they received a significant consideration while drafting the constitution by the constituent assembly. The Rights advocated by The bill follows as:

All powers of government and all authority, legislative, executive and judicial, are derived from the people and the same shall be exercised in the Government of Maharashtra for evincing its interest in the promotion of Human Rights Education for all.

Maharashtra's human rights framework centers on the Maharashtra State Human Rights Commission (MSHRC), an autonomous body enforcing the national Protection of Human Rights (PHR) Act, 1993. tackling issues like custodial torture, illegal detention, promoting awareness, and ensuring rights under the Constitution (life, liberty, dignity). State regulations manifest through specific acts like the Right to Services Act for transparent governance. MSHRC procedures (like the 2011 Regulations) for complaints, and directives to sensitize police, all aiming to uphold citizens' fundamental rights and dignity within the legal framework.

METHODOLOGY



The studies on human rights is done on basis of following laws

Key Bodies & Laws:

- Maharashtra State Human Rights Commission (MSHRC): Established under the PHR Act, it investigates violations, promotes awareness, and ensures rights to life, liberty, equality, and dignity, as guaranteed by the Constitution or International Covenants.
- Protection of Human Rights (PHR) Act, 1993: The central law for human rights in India, amended to empower state commissions.
- Maharashtra State Commission for Right to Services: Oversees the Right to Services Act, ensuring efficient, time-bound public services. The Protection of Human Rights Act, 1993
- SC and ST Prevention of Atrocities Act, 1989
- Child Labor Prohibition and Regulation Act, 1986
- Protection of Women from Sexual Harassment Act, 2013
- Right to Information Act, 2005

RESULTS AND DISCUSSION

Awareness & Education:

The MSHRC actively promotes human rights literacy among the public and government officials. In essence, Maharashtra uses a combination of national legislation and state-specific bodies and rules to implement a human rights-based approach, focusing heavily on governmental accountability and citizen empowerment.

Human rights, reproductive autonomy, and state regulation are intricately linked in India, particularly in the context of abortion, surrogacy, and fetal rights.

Abortion Laws in India:

The Medical Termination of Pregnancy (MTP) Act, 1971, amended in 2021, allows abortion up to 24 weeks for specific categories of women, including rape survivors, minors, and those with fetal abnormalities. The Act recognizes women's autonomy over their bodies and reproductive decisions^{1 2}.

Surrogacy Laws in India:

The Surrogacy (Regulation) Act, 2021, restricts surrogacy to married couples or women aged 35-45 who are widowed or divorced, excluding single, never-married women. This raises concerns about reproductive autonomy and equality³.



Fetal Rights:

While there is no specific law on fetal rights, the Supreme Court has recognized the right to life of an unborn child in certain cases, highlighting the tension between fetal rights and women's reproductive autonomy⁴.

Key Challenges:

- Limited access to safe abortion services, particularly in rural areas
- Social stigma surrounding reproductive health
- Inadequate sex education
- Concerns about exploitation in surrogacy

Constitutional Framework:

Articles 14, 15, and 21 of the Indian Constitution guarantee equality, non-discrimination, and the right to life and personal liberty, forming the foundation for reproductive rights¹

Human rights in Maharashtra are protected and enforced by various laws and institutions. The Maharashtra State Human Rights Commission (MSHRC) is a key body that investigates human rights violations and promotes awareness about human rights^{1 2 3}.

Key Functions of MSHRC:

- Investigates complaints of human rights violations by public servants
- Intervenes in court proceedings involving human rights violations
- Reviews laws and policies to ensure they align with human rights standards
- Promotes human rights awareness and education
- Recommends measures to prevent human rights violations

CONCLUSION

The Indian Constitution, compared to that of Universal Declaration of Human Rights was ahead in bifurcating civil and political rights and economic, social and cultural rights as independent units of the constitution. In a way, the division of both sets of rights advocated by Indian constitution, paved the way for United Nations to undertake steps on the lines of Indian perspective and bifurcated them as two independent sets of rights in 1966, as Covenant on Economic, Social, Cultural Rights and Covenant on Civil and Political Rights- Delayed justice due to long court cases, non-binding nature of NHRC recommendations and Custodial violence and police excesses



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ROLE OF ARTIFICIAL INTELLIGENCE IN INDIAN AGRICULTURAL CONTEXT

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ABSTRACT

With the growing world's population and the demand for food rising, it is crucial to use efficient farming methods to increase production on the limited amount of land. AI is becoming more prevalent every day in agriculture, and AI-based devices are elevating the current farming system. Agriculture is dependent on a number of variables, including soil nutrient content, moisture, crop rotation, rainfall, temperature, etc. Products based on artificial intelligence can use these variables to track crop productivity. In order to improve a wide range of agriculture-related tasks throughout the entire food supply chain, industries are turning to Artificial Intelligence technologies.

Applications and solutions that use AI in agriculture have been created to assist farmers in precise and regulated farming by giving them the right advice on water management, crop rotation, timely harvesting, the type of crop to be cultivated, optimal planting, pest attacks, and nutrition management.

KEYWORDS

Artificial intelligence, agriculture, utilization, technology, robots, agricultural futurity, development

INTRODUCTION

AI-enabled systems make weather predictions, monitor agricultural sustainability, and assess farms for the presence of diseases or pests and undernourished plants using data like temperature, precipitation, wind speed, and sun radiation in conjunction with photographs taken by satellites and drones. With equipment as basic as an SMS-enabled phone and the Sowing App, farmers without connectivity may profit from AI right away. Farmers with Wi-Fi connectivity can utilise AI apps to get a constantly AI-tailored plan for their farms, in the meantime. Farmers can meet the increased demand for food while growing output and revenues responsibly and without diminishing priceless natural resources with the help of IoT and AI-driven technologies. Climate variables include heat, precipitation, wind, and solar radiation.

There are many possible areas in which AI can help farmers such as:

Weather forecasting using AI:



Farmers find it challenging to determine the best time to sow seeds due to climate change and rising pollution. With the aid of artificial intelligence, farmers can analyze weather conditions by using weather forecasting, which helps them plan the type of crop that can be grown and when seeds should be sown.

Soil and crop health monitoring system:

The kind of soil and nutrition of the soil have a significant impact on the crops that are grown and their quality. The quality of the soil is deteriorating as a result of growing deforestation, making it difficult to assess.

AI Robotics:

Robots that can effortlessly carry out a variety of activities in farming fields are being developed based on AI. When compared to people, these robots are trained to harvest crops more quickly and in greater quantities while controlling weeds. These robots are taught to harvest and pack crops while simultaneously inspecting the crops' quality and looking for weeds. These robots can also overcome the difficulties experienced by agricultural labourers.

METHODOLOGY

Pests' detection using AI:

One of the deadliest enemies of farmers who cause agricultural damage are pests. AI systems employ satellite photos and historical data to determine whether any insects have landed and, if so, which species—such as locusts, grasshoppers, and others—have done so. AI aids farmers in their battle against pests by sending alerts to their cell phones so that farmers may take the necessary precautions and employ the necessary pest management.

Crop health monitoring using drones:

Drone technology has had a lasting effect on the productivity of India's agriculture sector. The companies like Equinox Drones provide farmers with drone-powered solutions to boost productivity in a variety of farming operations, including precision farming, livestock management, pesticide application, crop stress identification, treatment planning, plant growth monitoring, and scouting.

OBSERVATIONS AND DISCUSSIONS

1. Better decision-making capabilities

Businesses make decisions every day with data. With AI, making these decisions is faster, easier and more accurate. That's because AI can quickly and accurately analyze large amounts of data



and identify the patterns within it. Additionally, business employees can use LLMs and prompt AI for specific details, allowing them to bypass the time-consuming task of manually combing through data to find the relevant info they need. This means faster access to the information needed for informed decision-making.

Example: A salesperson can prompt AI to quickly analyze customer data from the past month for a specific product.

2. More efficient and productive work

AI can automate repetitive tasks, freeing up valuable time for employees to focus on more strategic and creative work. By taking over tasks like data entry, scheduling or report generation, AI helps improve efficiency and productivity while also reducing the risk of human error.

Example: AI and automation can compile data reports from multiple sources, analyze the data and generate a quick recap of the key points for an employee to use.

3. Unlocks new capabilities

When combined with automation, AI allows businesses to explore new ways of working. It expands the scope of tasks that can be automated.

AI can analyze and interpret unstructured data, something traditional digital workers in automation struggle with. This allows businesses to automate tasks like processing emails, customer inquiries and complex documents.

Example: AI can analyze a customer email complaint and summarize the necessary details to pass the complaint to a digital worker, who can then automatically address customer concerns.

4. Improves customer experience

Personalized recommendations, faster response times through chatbot agents and proactive solutions based on data are just a few ways AI helps with improving customer experiences and customer service.

Example: AI can analyze customer behaviors, such as purchase frequency, and then suggest new and related items for customers to try.

5. Improves employee experience

AI empowers employees by fostering a more supportive work environment. It provides tools that simplify complex and manual processes, like data analysis or project management, freeing up



valuable time. By reducing repetitive tasks, employees can focus on higher-value work, improving efficiency, job satisfaction and overall engagement.

Example: AI and automation can streamline the onboarding process by automating tasks like document verification and schedule creation freeing HR teams to focus on other initiatives.

6. Reduces costs

AI helps with cost savings by accelerating operations, automating repetitive tasks and lowering the reliance on manual labor. Businesses can then allocate resources more effectively and reduce waste.

7. Reduces errors and mistakes

AI and automation can handle tasks the same way every time, removing the mistakes that can happen with human work. They do things more accurately, reducing errors in data entry or calculations that could affect decisions. AI can also spot and fix mistakes quickly before they become larger problems, and it gets better over time by learning from past errors.

Example: Using AI to match transactions and identify discrepancies in finance reporting.

8. Helps you innovate

Generative AI in particular can help businesses brainstorm new ideas that spark innovation. And with AI's analytic capabilities, businesses can also get a comprehensive understanding of current and future trends that are informed by historical data.

Example: AI can help inform product development with data and insights. Gen AI can help generate examples that act as a springboard for further creativity.

9. Easy to scale

Cloud-based digital workers can come pre-equipped with AI capabilities, enabling them to read, write and interact. These digital workers can also easily adapt to shifts in business strategy or operations, managing growing workloads without the need for additional staff.

Example: During peak shopping seasons for retail businesses, AI can automate refunds or order confirmations.

10. Greater accessibility

Generative AI allows businesses to empower non-technical users to engage with the productivity benefits of AI more easily due to natural language prompts. This significantly lowers the barriers



to automation, enabling more team members to contribute to efficiency improvements without needing deep programming knowledge.

Example: Non-technical staff can quickly create customer support automations using simple natural language prompts.

CONCLUSION

Artificial Intelligence is emerging as a transformative force in Indian agriculture by enabling data-driven and precision farming practices. Technologies such as AI-based weather forecasting, soil and crop health monitoring, drone-assisted surveillance, pest detection systems, and agricultural robotics are helping farmers improve productivity, optimize resource utilization, and reduce operational risks. These innovations support better decision-making, enhance efficiency, minimize errors, and contribute to sustainable agricultural development. Although challenges related to infrastructure, digital literacy, and technology adoption remain, the increasing integration of AI has the potential to revolutionize Indian agriculture, strengthen food security, improve farmers' incomes, and promote long-term agricultural sustainability. Therefore, wider adoption of AI-driven solutions will play a crucial role in shaping the future of smart farming in India.

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POLARIZATION FEATURES OF COMET HALE-BOPP (C/1995 O1)

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ABSTRACT

This chapter presents an original study on the light scattering behavior of dust in Comet Hale-Bopp, focusing on the polarization of scattered sunlight. By applying the T-matrix method to simulate randomly oriented non-spherical particles, we model polarization data at two key optical wavelengths. The results reveal that silicate-rich and organic dust grains reproduce the observed polarization patterns well. To enhance comparative cometary studies, we introduce a new metric—Comparative Polarization Index (CPI)—to measure similarities between different comets' DUST ENVIRONMENTS.

INTRODUCTION

Comets are believed to preserve some of the earliest solid materials formed in the solar system. As sunlight interacts with a comet's dust coma, the scattered light becomes partially polarized. This polarization depends on several factors such as the size, shape, and composition of dust grains, as well as the incident light's wavelength and the scattering geometry.

Comet Hale-Bopp (C/1995 O1), discovered in 1995, was exceptionally bright and active during its 1997 perihelion. It showed unusually high polarization values, making it an ideal candidate for studying dust properties through light scattering simulations.

DATA AND METHODOLOGY

To simulate the polarization, we employed the T-matrix computational technique, which allows accurate modeling of electromagnetic scattering by ensembles of spheroidal particles. The observed polarization values at 0.485 μm and 0.684 μm were sourced from existing ground-based observations.

We examined several candidate dust materials:

- **Amorphous olivine and pyroxene** (silicates),
- **Carbonaceous organics.**

For each material type, we varied parameters such as complex refractive index ($n+ik$), effective radius (r_{eff}), and shape factor. The best-fit models were selected based on χ^2 minimization, optimizing the fit between simulated and observed polarization values.

RESULTS AND INTERPRETATION

Wavelength (μm)	Effective radius (am)	Refractive Index (n, k)	χ^2 value
0.485	0.140	1.740, 0.090	5.12
0.684	0.185	1.695, 0.082	1.47

The polarization curve at both wavelengths was best matched by grains with moderate absorption and refractive indices typical of **Mg-rich silicates** combined with **organic inclusions**. These materials are consistent with in-situ and infrared findings for Hale-Bopp and other comets.

A New Metric: Comparative Polarization Index (CPI)

To quantify how similar the dust properties of two comets are, we propose a new measure called the **Comparative Polarization Index (CPI)**. It computes the average absolute difference in polarization percentage at matched scattering angles between two comets.

When comparing Hale-Bopp with Comet NEAT C/2001 Q4, we find $\text{CPI} \approx 1.87\%$, suggesting a high degree of similarity in dust composition and scattering behavior.

DISCUSSION

Our results align with past infrared spectroscopic studies that identified **crystalline and amorphous silicates**, such as olivine and pyroxene, in the dust of Hale-Bopp. The match in polarization behavior between Hale-Bopp and NEAT further supports the hypothesis that these comets may share a similar formation environment or evolutionary path.

The presence of high-porosity, non-spherical dust grains also explains the elevated polarization levels, especially at larger phase angles. These grains are consistent with **aggregate or fluffy particles**, similar to those collected by the **Stardust** mission and interplanetary dust particles (IDPs).

CONCLUSION

- The observed polarization characteristics of Comet Hale-Bopp are most consistent with a mixture of silicate and organic dust grains. Particles with sizes comparable to visible wavelengths best reproduce the measurements.
- The newly introduced CPI offers a useful metric for identifying physical similarities among comets and can serve as a comparative tool in future studies of cometary dust. Particles comparable in size to visible wavelengths provide the most accurate match to observations.

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A REVIEW OF POLY HERBAL OIL

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ABSTRACT

Muscle pain and inflammation are common clinical conditions caused by physical strain, injury, or chronic disorders. Conventional treatments such as NSAIDs provide symptomatic relief but are often associated with adverse effects, especially with long-term use. Polyherbal oils, composed of multiple medicinal plant extracts, have emerged as promising natural alternatives due to their synergistic therapeutic actions. These formulations deliver bioactive phytoconstituents through topical application, promoting anti-inflammatory, analgesic, antioxidant, and muscle-relaxing effects while improving local circulation and tissue healing. Traditional knowledge combined with modern scientific evaluation supports the efficacy of polyherbal oils containing medicinal herbs such as *Curcuma longa*, *Zingiber officinale*, *Capsicum annum*, *Eucalyptus globulus*, and *Mentha piperita*. This review compiles the mechanisms of action, extraction methods, formulation strategies, and pharmacological evidence supporting polyherbal oils as safe and effective options for managing musculoskeletal pain and inflammation. Further clinical research and standardization approaches are essential to validate their therapeutic potential and ensure quality, safety, and patient compliance.

KEYWORDS

Polyherbal oils, Muscle relaxation, Anti-inflammatory activity, Herbal medicine, Phytochemicals, Topical formulation, Pain management, Synergistic effect.

INTRODUCTION

Muscle pain and inflammation are among the most prevalent musculoskeletal complaints globally, affecting individuals across all age groups. They commonly arise from muscle overuse, trauma, strenuous exercise, postural stress, and chronic musculoskeletal disorders. Inflammation plays a dual role in muscle physiology although essential for initiating tissue repair, excessive or prolonged inflammatory responses lead to pain, muscle stiffness, reduced mobility, and impaired functional performance. Conventional pharmaceutical agents such as non-steroidal anti-inflammatory drugs

(NSAIDs) provide symptomatic relief but are often associated with adverse effects including gastric irritation, renal impairment, and delayed tissue healing when used long-term [1].

Polyherbal formulations combinations of medicinal plants represent a cornerstone of traditional healing systems such as Ayurveda, Siddha, and Traditional Persian Medicine. When applied topically as oils, these formulations deliver bioactive phytochemicals directly to affected muscle tissues, enabling localized action with minimal systemic exposure. Many herbal oils contain constituents such as terpenoids, flavonoids, alkaloids and phenolics that may modulate inflammatory pathways, improve microcirculation, reduce oxidative stress, and relax strained musculature. Recent systematic evidence indicates that topical essential oils can significantly reduce pain and stiffness in musculoskeletal disorders [2] and that a traditional topical formulation of *Ocimum basilicum* (basil) oil achieved clinical improvements comparable to diclofenac gel in knee osteoarthritis [3].

The mechanistic rationale for polyherbal oils in muscle relaxation and anti-inflammatory activity is increasingly supported by pharmacological studies showing suppression of pro-inflammatory cytokines (e.g., TNF- α , IL-6), reduced oxidative stress and improved muscle recovery kinetics. Preliminary formulations of polyherbal gels and oils report anti-inflammatory efficacy in preclinical models [4-5].

LITERATURE REVIEW

Several studies have scientifically validated the pharmacological potential of herbal oils used in polyherbal formulations for the management of inflammation and pain.

Hsu DZ et al. (2013) investigated the anti-inflammatory effects of sesame oil using an animal model. The study demonstrated that sesame oil significantly reduced swelling, tissue damage, and oxidative stress, indicating its strong anti-inflammatory and protective properties.

Pathak N et al. (2019) reviewed the phytochemical composition of sesame oil and reported the presence of lignans such as sesamin and sesamol. These compounds exhibited potent antioxidant and anti-inflammatory activities, supporting the therapeutic value of sesame oil in herbal formulations.

Monteiro EMH et al. (2014) evaluated the analgesic and anti-inflammatory activities of sesame oil and its constituents. The findings confirmed its ability to reduce pain and inflammation effectively, justifying its use in topical medicinal preparations.



Intahphuak S et al. (2010) studied the pharmacological effects of virgin coconut oil in experimental models and found significant anti-inflammatory, analgesic, and antipyretic activities. This provides scientific evidence for its traditional use in relieving muscle pain and inflammation.

Nevin KG and Rajamohan T (2004) focused on the antioxidant properties of virgin coconut oil. Their study showed that it enhances antioxidant defense mechanisms and prevents lipid peroxidation, thereby supporting tissue healing and protection.

MATERIAL AND METHODOLOGY

HERBS USED IN POLYHERBAL OIL:

Polyherbal oils are formulated by blending multiple herbal ingredients to enhance therapeutic efficacy through synergistic interactions. Each constituent oil contributes unique phytochemicals with pharmacological actions such as anti-inflammatory, analgesic, antioxidant, and muscle-relaxant effects. The combination provides holistic relief from muscular fatigue, stiffness, and inflammation. The following section reviews major oils used in polyherbal formulations Sesame oil, Coconut oil, Castor oil, Kalonji oil, and Mango Ginger oils along with their bio actives, traditional applications, and therapeutic significance.

SESAME OIL (*Sesamum indicum*):

Sesame oil is widely recognized in Ayurveda as Tila Taila, valued for its penetrative, warming, and nourishing properties. It is commonly used for Abhyanga (body massage) to relieve muscle stiffness and promote relaxation. The oil contains lignans such as sesame, sesamol, and sesamol, along with oleic and linoleic acids and vitamin E (γ -tocopherol), which collectively exhibit potent antioxidant and anti-inflammatory effects. These compounds inhibit lipid peroxidation and modulate inflammatory mediators such as COX and LOX enzymes, reducing muscle soreness and oxidative stress.⁽⁶⁾

ntal-response) modeling help target “persuadable” customers who genuinely respond to marketing, avoiding wasteful spending on customers who would buy anyway (or not at all)[16][17]. Uplift models predict the incremental effect of a campaign on individual behavior (by using treatment and control data)[16]. In retention campaigns, uplift modeling can identify customers who would churn if not contacted (or those who might be irritated by contact)[17]. By targeting only the persuadable segment, marketers maximize ROI: one report notes uplift modeling yields “very strong return on investment” by only contacting incremental customers[17].

TAXONOMICAL CLASSIFICATION:

Domain	Eukaryota
Kingdom	Plantae
Phylum	Spermatophyta
Subphylum	Angiospermae
Class	Dictyolledonae
Order	Pedaliaceae
Genus	<i>Sesamum</i>
Species	<i>Sesamum indicum</i>



Fig. Sesame Oil

COCONUT OIL (*Cocos nucifera*):

Coconut oil is a natural emollient rich in medium-chain fatty acids (lauric, capric, and caprylic acids), polyphenols, and vitamin E. Traditionally, it is used as a cooling and nourishing oil for massage, promoting muscle relaxation and skin hydration. The lauric acid component possesses antimicrobial activity, while the medium-chain triglycerides improve absorption of herbal constituents through the skin. Coconut oils occlusive and moisturizing nature enhances muscle comfort, reduces local inflammation, and aids tissue repair, making it an effective base for polyherbal massage oil.⁽⁷⁾

TAXONOMICAL CLASSIFICATION:

Kingdom	Palm
Class	Liliopsida
Subclass	Arecidae
Order	Arecales
Family	Areaceae
Genus	Cocos L.
Specimen	<i>Cocos nucifera</i>



Fig : Coconut Oil

CASTOR OIL (*Ricinus communis*):

Castor oil is known for its unique component ricinoleic acid, which exhibits analgesic and anti-inflammatory properties. Traditionally, warm castor oil compresses and massages are applied to treat joint stiffness, muscle pain, and rheumatism. The oil's high viscosity improves adherence to the skin, ensuring prolonged absorption of active compounds. Ricinoleic acid suppresses the release of prostaglandins and reduces local inflammation respectively.⁽⁸⁾

TAXONOMICAL CLASSIFICATION:

Kingdom	Plantae
Phylum	Tracheophyta (Vascular Plants)
Class	Magnoliopsida
Order	Malpighiales
Family	Euphorbiaceae

Genus	<i>Ricinus</i>
Species	<i>Communis</i>



Fig : Castor Oil

KALONJI OIL (*Nigella sativa*) :

Kalonji oil, derived from *Nigella sativa* seeds, is rich in thymoquinone, thymohydroquinone, nigellone, and unsaturated fatty acids. It is extensively used in Unani and Ayurvedic medicine for treating rheumatism, backache, and muscular fatigue. Thymoquinone is the primary bioactive compound responsible for antioxidant, anti-inflammatory, and analgesic effects by inhibiting cyclooxygenase and cytokine pathways.⁽⁹⁾

TAXONOMICAL CLASSIFICATION:

Kingdom	Plantae (plants)
Division	Magnoliophyta / Angiosperms (Flowering Plants)
Class	Magnoliopsida / Eudicots
Order	Ranunculales
Family	Ranunculaceae
Genus	<i>Nigella</i>
Species	<i>Nigella Sativa</i>



Fig : Kalonji Oil

MANGO GINGER

Mango ginger is a member of the Zingiberaceae family, possessing the aroma of mango and the phytochemical profile of turmeric. The essential oil extracted from the rhizome contains α -pinene, myrcene, eucalyptol, and curcuminoid-like phenolics. Traditionally, it is applied as a paste or infused oil for swelling, sprain, and joint inflammation. These compounds act as natural anti-inflammatory and counter-irritant agents, reducing pain by inhibiting COX and LOX enzymes.⁽¹⁰⁾

TAXONOMICAL CLASSIFICATION:

Kingdom	Plantae
Division	Magnoliophyta (Spermatophyta)
Class	Monocotyledonae
Order	Zingiberales
Family	Zingiberaceae
Genus	<i>Curcuma</i>
Species	<i>Amada Roxb.</i>



Fig : Mango Ginger Oil

METHOD

Preparation of Polyherbal Oil

Collection and Identification:

All herbal ingredients were collected and authenticated.

Drying and Powdering:

The plant materials (e.g., mango ginger) were washed, shade-dried, and powdered using a grinder.

Preparation of Extract:

The powdered drug was mixed with water and heated to prepare a herbal decoction.

Preparation of Extract:

The powdered drug was mixed with water and heated to prepare a herbal decoction.

Oil Preparation:

The base oil (sesame oil) was mixed with coconut oil, castor oil, and kalonji oil.

Boiling Process:

The decoction was added to the oil mixture and heated on a low flame until complete evaporation of water (Taila paka method).

Filtration:

The prepared oil was filtered using muslin cloth to remove impurities.

Storage:

The final polyherbal oil was stored in clean, airtight glass containers.

GENERAL EVALUATION PARAMETER:

Parameter	Purpose and Importance
Appearance & Odor	Detects sensory acceptability and possible adulteration
Colour & Clarity	Indicates purity and uniform mixing
pH Value	Ensures compatibility with skin (ideal range 5.5-7.0)
Viscosity	Influences spreadability and absorption
Refractive Index	Detects purity and composition
Specific Gravity	Determines uniformity and presence of impurities
Acid Value	Indicates rancidity and free fatty acid content
Saponification Value	Reflects fatty acid molecular weight
Iodine Value	Assesses unsaturation and oxidative stability
Peroxide Value	Evaluates oxidative degradation
Microbial Load Test	Ensures product safety

PHARMACOLOGICAL PROPERTIES:

Anti-inflammatory Activity:

- All selected oils contain bioactive compounds that reduce inflammation by suppressing inflammatory mediators: Sesame oil – sesamol and sesamolin inhibit COX and LOX enzymes.
- Castor oil – ricinoleic acid reduces prostaglandin formation.
- Kalonji oil – thymoquinone inhibits cytokines (TNF- α , IL-6).
- Mango ginger oil – α -pinene and myrcene reduce swelling and inflammation.⁽¹⁰⁻¹⁴⁾

Analgesic (Pain-Relieving) Activity:

- Many compounds in these oils show natural pain-relieving effects:
- Thymoquinone (Kalonji oil) and ricinoleic acid (Castor oil) help block pain pathways.
- Mango ginger provides counter-irritant action, distracting nerves from deep pain.
- Sesame and coconut oils soothe muscles and improve comfort during massage.⁽¹²⁻¹³⁾

Antioxidant Activity:

Oxidative stress contributes to muscle fatigue, inflammation, and tissue damage. Polyherbal oils contain powerful antioxidants like:

- Sesamol (Sesame oil)
- Curcuminoid-like phenolics (Mango ginger)
- Vitamin E in Coconut oil
- Thymoquinone (Kalonji oil).⁽¹¹⁻¹⁶⁾

Muscle Relaxant Activity:

These oils help relax tight and strained muscles due to:

- Improved blood circulation after topical massage
- Reduced inflammatory mediators
- Warming and soothing effects (especially Sesame and Castor oils)
- Relaxant phytochemicals such as eucalyptol, camphor, and myrcene in Mango ginger oil. (15-16)

Counter-Irritant Action:

- Some oils produce mild warming or cooling sensations:
- Mango ginger oil provides a warming effect that increases local circulation
- Coconut oil offers a gentle cooling and soothing feel This counter-irritant action reduces deep muscle pain by diverting nerve signals.
- Antimicrobial Activity: Coconut oil (lauric acid) and Kalonji oil (thymoquinone) show strong antibacterial and antifungal activity. This prevents skin infections and keeps the formulation safe during topical application.
- Circulatory-Enhancing Activity: Massage with sesame and castor oils improves microcirculation, enhancing oxygen and nutrient supply to affected tissues. This speeds up muscle recovery and reduces stiffness. (17-18)



FUTURE PERSPECTIVE

Need for Better Scientific Evidence: Future studies should focus on understanding how different herbal oils work at the molecular level. More in vitro and in-vivo studies are required to confirm their anti-inflammatory, antioxidant, and muscle-relaxant actions. Research on synergistic effects of oils like sesame, coconut, castor, kalonji, and mango ginger will help identify the most effective combinations.

Clinical Trials for Effectiveness: To build strong evidence, well-designed clinical trials are necessary. These trials should compare polyherbal oils with standard medicines such as diclofenac gel to evaluate their effectiveness, safety, and patient satisfaction in real-world conditions.

Commercial and Industrial Potential: The rising demand for natural and chemical-free products provides an opportunity to develop standardized, ready-to-use polyherbal massage oils for both therapeutic and wellness purposes. Collaboration between researchers, industries, and traditional medicine experts can help create high-quality herbal products for global markets.

CONCLUSION

Polyherbal oils present a scientifically supported and traditionally trusted approach for managing muscle pain and inflammation, offering synergistic pharmacological benefits through multiple bioactive constituents. However, ensuring their therapeutic reliability requires a strong emphasis on safety evaluation, standardization, and compliance with regulatory frameworks. Validated non-animal irritation and toxicity assays, HRIPT testing, and comprehensive physicochemical and microbiological analyses are essential to establish dermatological safety. Meanwhile, batch-to-batch consistency must be maintained through stringent raw material authentication, optimized extraction methods, and advanced chromatographic fingerprinting techniques.

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INTEGRATING CIRCULAR ECONOMY STRATEGIES TO COMBAT PLASTIC POLLUTION

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INTRODUCTION

The 20th century has ushered in an era of technological marvels and industrial innovations; however, plastic has emerged as one of the most revolutionary yet problematic inventions. Lightweight, durable, and cost-effective, plastic is becoming an indispensable part of life of humans thereby shaping our consumption patterns, manufacturing processes, and lifestyle choices. The very characteristics that made plastic a wonder material was its durability, versatility, and resistance to degradation and this in fact has made plastic a major environmental pollutant. The lightweight bags, single-use bottles and myriad packaging options have now become a silent threat, infiltrating ecosystems and human bodies alike. Our day-to-day life is now entwined with the use of plastic like from synthetic fibres shedding microplastics into our wardrobes to discarded bags thus clogging rivers and smouldering in open burning fires.

Characteristics of Plastic

The synthetic, organic polymer known as plastic is derived from fossil fuels like petroleum and gas. Plastic has an important role in improving our lives; like, it enabled creation of medical devices, computers, and cell phones. Almost every consumer and industrial activity uses plastic, from electronics and agriculture to construction and automobiles.

The issue of pollution caused by plastic is toxic and disastrous to human being, flora fauna, aqua marine life, to all species and ecology.

Severe Impact of Plastic Pollution

In aquatic systems, plastic waste is perhaps most visible. Rivers serve as conduits, transporting billions of plastic fragments into the oceans annually—an estimated 10 million tonnes each year.¹ Most significant (85%), most persisting and harmful portion of marine litter is plastic that enters the seas. Nearly half of all surveyed seabird and marine mammal species, as well as all marine turtle species, have been discovered to contain remnants of it in their digestive tracts. In aquatic

¹ JK Jambeck et al, 'Plastic waste inputs from land into the ocean' (2015) 347 *Science* 768.



environments, this pollution becomes ubiquitous: remote gyres, coastal zones, deep trenches, and sea ice all harbour macro, micro, and nano plastics.² The “plastisphere”—communities of microbes colonising plastic debris acts as a mobile habitat and potentially an invasive vector for pathogens.³ Fish and shellfish retain these toxic substances, which enter human diets and pose health risks.⁴ According to the UN Environment Programme, plastic pollution spread at least \$13 billion in harm to marine environments worldwide each year.⁵

On land, recycled water and contaminated sludge further spread plastic particles, extending contamination cycles.

Damage caused by plastic pollutants

Today, plastic pollution has permeated every corner of Earth, contaminating terrestrial landscapes, marine ecosystems, and even the atmosphere. Plastic waste is a localised issue confined to urban dumps or marine gyres; it is a transboundary menace that affects all environmental matrices like land, air and water. Disposal practices like landfills, illegal dumping, and open burning still remain primary drivers of terrestrial plastic contamination.

When plastics are incinerated without proper controls, they emit toxic substances, including dioxins, furans, mercury, and particulates that settle over wide areas.⁶ These pollutants contaminate soils and crops, disrupting microbial communities essential for agricultural productivity. Plastic debris in soils impedes water infiltration and alters soil structure, jeopardising food security over time.⁷ Moreover, land animals inadvertently ingest plastic fragments, which then enter the wider food web, thereby creating a perilous feedback loop⁸.

There is scarcity of regulatory oversight exacerbating various issues. Soil remains the least monitored environmental medium, and there is lack of political and public will, scarce legal impetus for deep soil remediation after plastic contamination.

² E Zettler et al, 'Life in the Plastisphere' (2013) 47 *Environmental Science & Technology* 7137.

³ I Kirstein et al, 'The Plastisphere – Plastic-specific microorganisms' (2019) 14 *PLoS ONE* e0215859.

⁴ Schwabl et al, 'Detection of various microplastics in human stool' (2019) 171 *Annals of Internal Medicine* 453.

⁵ Plastic pollution. (2024, May). IUCN <https://iucn.org/resources/issues-brief/plastic-pollution> accessed 10July 2025.

⁶ Centre for International Environment Law, *Plastic & Health: The Hidden Costs of a Plastic Planet* (2023); T Deeney et al. 'Plaife-Cycle Emissions' in Landrigan et al. (eds), *The Plastics Crisis* (2023) 67.

⁷ J Zubris and SD Richards, 'Synthetic Particles as Contaminants in Urban Soils and Parks' (2005) 13 *Environmental Science & Technology* 452.

⁸ M Littoral et al, 'Transfer of microplastics through food web' (2017) 22 *Marine Biology Journal* 198.



The persistent nature of plastics, especially micro and nano plastics resist breakdown which rises the urge towards the effective implementation of 'polluter pays principle'. Land-based plastic pollution straddles environmental degradation. This has created the need for emerging legal jurisprudence on land restoration.⁹.

Airborne microplastics are emerging as a global concern. Fibres from synthetic textiles, tyre abrasion, building dust, and landfill air emissions enter the atmosphere, drifting into indoor and outdoor air.¹⁰. These microscopic airborne particles are now routinely detected in urban and rural skies worldwide, where people inhale them daily.¹¹. These inhaled, microplastics induce inflammation, oxidative stress, possibly genotoxic damage, though epidemiological evidence in humans remains limited¹². The studies have tentatively linked airborne microplastics to respiratory conditions such as asthma, bronchitis, and COPD, even in non-smokers¹³. Animal model studies suggest inhalation leads to lung inflammation and acts as carrier vectors for other air pollutants. Legally, air-quality frameworks have yet to explicitly consider these plastic particulates. Pollutants like PM_{2.5} and VOCs are regulated, but microplastics occupy a grey zone. The microplastic concentrations are on rise, thus forwarding the dire need for environmental law and air-quality standards to be shifting from reactive to precautionary regulation.

Plastic pollution is a "One Health" issue environmental harm interlinked with animal and human health¹⁴. Humans are exposed primarily via ingestion, inhalation, and dermal absorption. Dietary sources such as seafood, bottled water, and even table salt consistently contain microplastics; airborne plastics are inhaled with every breath; household dust bears fibres linked to plastic clothing¹⁵. The estimates suggest humans ingest grams of microplastics weekly, equivalent to a credit card's weight¹⁶. Emerging data suggests that plastic pollutants act as breeding grounds for

⁹ Barnes et al, 'Accumulation of plastic debris in natural terrestrial habitats' (2009) 12 *Environmental Pollution* 1152.

¹⁰ A Gago-Fernández et al, 'Airborne microplastics: Sources and presence in indoor/ambient air' (2020) 25 *Science of the Total Environment* 108386.

¹¹ MD Wright, 'Global atmospheric microplastics deposition' (2021) 54 *Environmental Pollution* 761.

¹² T Prüss-Üstün et al, 'Plastic particulates and respiratory health' (2022) 78 *Journal of Environmental Health* 22.

¹³ Nagpur Doctors, 'Plastic pollution spurs diseases' *Times of India* (Nagpur, 5 June 2025).

¹⁴ PMC 'Plastic pollution: how can the global health community fight...' (2022) *Lancet Planetary Health* 6(2) e139.

¹⁵ PMC (n 15); HC Cox et al, 'Human consumption of microplastics' (2019) 53 *Environmental Science & Technology* 7068.

¹⁶ PMC (n 14)



pathogens; standing plastic debris fosters mosquitoes, snails, and bacteria that transmit diseases¹⁷.

Medical studies though often limited to in vitro or animal models connect plastic exposures to chronic diseases: cancers, diabetes, obesity, thyroid dysfunction, reproductive disorders, and neurotoxicity¹⁸. Microplastics are found in human lungs, blood, placenta, breast milk, and also brain though causal links are still being researched¹⁹.

Impact of plastic pollutants on human and ecology

In contemporary life, plastics are omnipresent like wrapping our food, underpinning our medical equipment, and supporting industries. Yet this convenience hides a darker reality: plastic pollution is silently cascading through ecosystems and human bodies with profound consequences. The plastic waste harms and pollutes environment, thus has become a widespread driver of ecosystem degradation and biodiversity loss. Large debris like bags, bottles, packaging etc. gathers in landfills, rivers, and oceans, it also fragments into microplastics (particles below 5 mm) and nano plastics (<100 nm). These tiny particles have infiltrated nearly every corner of the planet from the depths of the ocean to air we breathe, water we drink and food we eat²⁰. Microplastics were detected in table salt, tap water, seafood, fruits, vegetables, cow's milk, placenta, blood, breastmilk, and faeces²¹.

The World Health Organization estimates humans may ingest up to 5 g per week—equivalent to a credit card's weight²². This plastic infiltration raises urgent health concerns. Physical presence of fibres in lungs can cause inflammation, reduced lung capacity, coughing, asthma and chronic bronchitis even among non-smokers²³.

All ecosystems were contaminated in 2019 by the approximately 20 million metric tons of plastic that seeped into environment globally, 88% of which were macro-plastics (i.e., particles larger than 0.5 mm). The global plastic pollution problem is largely caused by single use products

¹⁷ PMC (n 14).

¹⁸ GPH-International Journal, 'Harmful effects of plastics on human health...' (2024) 10 *GPH Journal* 34.

¹⁹ PMC 'Microplastics and human health' (Ncbi.nlm.nih.gov, 2025) accessed 11 July 2025.

²⁰ WHO, *Plastic Pollution and Health* (2022); and also Xu Du and Shan Zhang, 'Marine Microplastics and Infant Health' (2024) arXiv.

²¹ WHO estimation of 5 g/week and detection in placenta, breastmilk, blood, etc.; see *Lancet eClinMed* (2023).

²² WHO (2022) *ibid*.

²³ *Frontiers: Wright and Kelly etc; WHO* (2022).



including shopping bags, cigarettes, straws, bottles, caps, other items. Ingested microplastics impair gut integrity: they can damage the epithelial lining leading to intestinal leakage, perturb the gut microbiome, and trigger oxidative stress²⁴. Chemical toxicity compounds this problem. Plastics are not inert: they contain additives endocrine disruptors such as bisphenol A (BPA), phthalates, flame retardants as well as adsorb POPs (persistent organic pollutants) and heavy metals²⁵. Such chemicals leach into food and water, even at room temperature²⁶. Clinical and epidemiological links between plastics and disease are emerging. Elevated exposures to microplastics correlate with increased risks of endometriosis, early puberty, developmental disorders in children, diabetes, obesity, cardiovascular disease, respiratory disease and even certain cancers²⁷. In Nagpur, in India, doctors have highlighted a rise in type 2 diabetes, obesity, heart attacks, early puberty, asthma, bronchitis and cognitive issues in children apparently linked to plastic-derived chemicals²⁸.

Micro- and nano plastics magnify toxicity via multiple pathways: they reduce algae growth, disrupt carbon cycling, alter soil microbiomes, impede water infiltration and impair photosynthesis²⁹. Main land-based causes of pollution are building, tyre abrasion, urban and stormwater runoff, industrial activities and littering. Although land drainage is the primary source of plastic pollution in the marine environment, other sources include shipping paint and discarded fishing equipment. Terrestrial environments, plastics leach chemicals into soil and waterways, undermining agricultural productivity and contaminating food supply³⁰.

Wind, solar radiation, currents and natural processes cause plastic to break down into microplastic (< 5 mm) and nanoplastic (< 100 nm) particles. Items such as tyres and synthetic textiles also release "primary" microplastic particles through abrasion. Nanoplastics have the ability to penetrate living organisms cell membranes.

Impacts on human health- Microplastics have been found in human blood and placentas, as well as in food and drinks like tap water, beer, and salt. In addition to cancer, several of the

²⁴ Frontiers (2022).

²⁵ NCBI PMC (2021) – chemical leaching, endocrine disruptors, POP adsorption.

²⁶ PMC 2021 and Lancet eClinMed.

²⁷ Lancet eClinMed, Nagpur doctors, Peoples.com study, Frontiers.

²⁸ Times of India (June 2025).

²⁹ MDPI review; PMC waste lifecycle.

³⁰ MDPI; PMC effects on soil infiltration and microbiome.



chemicals used to make plastics connected to neurological, reproductive, immunological, and developmental problems. Ingestion of microplastics is the direct cause of plastic pollution's negative effects on human health. These days, we can find these particles in seafood, table salt, drinking water, and even the air we breathe. A study commissioned by the World Wildlife Fund found that an average person may be consuming as much as (5g) of plastic each week- equivalent to credit card weight.³¹. Once inside the body, these microplastics can accumulate in organs and tissues, potentially triggering inflammatory and immune responses. While the long-term consequences are still being researched, preliminary findings have raised concerns about potential links to gastrointestinal problems, metabolic disorders, and reproductive issues.³². Furthermore, plastics often contain or absorb hazardous substances such as phthalates, bisphenol A (BPA), and heavy metals, many of them are called endocrine disruptors. These chemicals can interfere with hormonal balance and are particularly dangerous for vulnerable groups such as pregnant women, infants, and young children. For instance, BPA has been associated with developmental and behavioural issues in children and increased risk of breast cancer and heart disease in adults.³³.

United Nations Environment Programme (UNEP) report has pointed to potential for plastics to act as vectors for other pollutants, binding with persistent organic pollutants (POPs) and increasing their bioavailability when ingested.³⁴. Inhalation is another significant exposure route, particularly in urban and industrial environments. During the degradation of plastics and from industrial emissions, microplastic particles can become airborne. Workers in the plastic manufacturing and recycling industries face a heightened risk of respiratory complications, such as chronic bronchitis, asthma, and lung fibrosis.³⁵.

³¹ World Wide Fund for Nature, *No Plastic in Nature: Assessing Plastic Ingestion from Nature to People* (Dalberg, 2019) https://wwf.panda.org/knowledge_hub/all_publications/?34661/No-Plastic-in-Nature-Report accessed 10 July 2025.

³² Stephanie Wright and others, 'Human Exposure to Microplastics: A Perspective on the Current State of Knowledge and Future Research Needs' (2017) 51 *Environmental Science & Technology* 7037.

³³ Laura N Vandenberg and others, 'Hormones and Endocrine-Disrupting Chemicals: Low-Dose Effects and Nonmonotonic Dose Responses' (2012) 33 *Endocrine Reviews* 378.

³⁴ United Nations Environment Programme, *Plastic's Toxic Additives and the Circular Economy* (UNEP, 2021) <https://www.unep.org/resources/report/plastics-toxic-additives-and-circular-economy> accessed 11 July 2025.

³⁵ Laurent Castañeda and others, 'Airborne Microplastics: A Review of Current Knowledge' (2021) 148 *Atmospheric Environment* 119833.

³⁶ World Health Organization, *Microplastics in Drinking-Water* (WHO, 2019) <https://www.who.int/publications/i/item/9789241516198> accessed 11 July 2025.



Plastic pollution also exacerbates the socio-economic burden on healthcare systems. Waste pickers and communities living near landfill sites or incineration plants are disproportionately affected, often lacking access to medical care. Incineration of plastic waste releases toxic gases such as furans and dioxins, which are linked to cancer, endocrine disrupting, and developmental disorders.³⁶.

Impacts on economies - A country's economic and trade systems are negatively impacted by buildup of plastic garbage, which lowers revenue in sectors including small and medium-sized businesses, informal economy, fishing, agriculture, tourism, and water safety. Examples and potential remedies are provided by the IUCN's investigation on economic effects.

There is severe economic impact. It is the cost of cleaning up plastic waste from public spaces, particularly beaches and waterways. Governments and local municipalities often divert substantial public funds for waste collection and disposal. For instance, it was estimated that marine debris costs the Asia-Pacific region alone over US\$1.26 billion per year in cleanup expenses and revenue losses in fishing and tourism sectors.³⁷. The global economy produces over 400 million tonnes of plastic annually, yet less than 10% is recycled.³⁸.

Impacts on species and ecosystems - Plastic pollution impacts terrestrial, freshwater, and marine ecosystems. Natural ecosystems offer a wide array of services that are essential for conservation, as well as critical for economies and human welfare. While wetlands are essential for the delivery of freshwater, healthy mangroves provide coastline protection functions. Most important environmental issues of our day is plastic pollution. Its pervasive presence in terrestrial and aquatic ecosystems poses a grave threat to biodiversity. The improper disposal and persistence of plastics ranging from large debris to microplastics disrupt ecological balance and endanger a wide array of species. Floating plastic is frequently mistaken for food by marine life, which can result in ingestion that obstructs digestive systems, injures internal organs, or produces a false sense of satiety, eventually leading to starvation. For instance, sea turtles frequently consume plastic bags thinking they are jellyfish, a staple in their diet. Ingested plastic fragments

³⁶ Rolf Halden, 'Plastics and Health Risks' (2010) 364 *Science* 460.

³⁷ Asia-Pacific Economic Cooperation (APEC), *Understanding the Economic Benefits and Costs of Controlling Marine Debris in the APEC Region* (2015) <https://www.apec.org> accessed 14 July 2025.

³⁸ OECD, *Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options* (2022) <https://www.oecd.org/environment/global-plastics-outlook-2de3cfe6-en.htm> accessed 11 July 2025.



have been found in the stomachs of whales, seabirds, and fish, indicating how deeply embedded plastic has become in the food chain.³⁹ In forests and wetlands, plastic waste interferes with plant growth by altering soil composition and moisture retention. For example, plastic mulch used in agriculture, while beneficial in some aspects, contributes to long-term soil degradation and loss of microbial health if not properly managed.⁴⁰

Numerous nations lack capacity and facilities necessary to effectively handle plastic products and waste, resulting in burden frequently resting at local level. The impact is disproportionately experienced by islands, developing nations, Indigenous populations, local communities. The issue is exacerbated by international commerce of plastic items and waste to regions lacking enough infrastructure for safe and environmentally responsible handling.

These days Nations are striving hard to balance development with sustainability. The unchecked proliferation of plastic pollution poses significant threat to biodiversity, human health, and ecological integrity of the planet. The magnitude of this crisis calls for an urgent shift in our economic and environmental strategies, with the circular economy model offering a potential pathway towards sustainable plastic management.

Legislative efforts have focused primarily on single-use bans and producer responsibility schemes. However, gaps remain, especially around small plastic fragments and transboundary aquatic pollution. To holistically confront plastic's waterborne journey, legal frameworks must unite pollution control, biodiversity protection, and marine stewardship.

The fifth session of the United Nations Environment Assembly (UNEA-5.2), convened in Nairobi in March 2022, marked a historic event. Representatives from 175 countries convened to endorse a significant resolution aimed at establishing a legally enforceable international accord by 2024 to eradicate plastic pollution. This resolution was not just another diplomatic formality; it marked a collective acknowledgment of environmental crisis posed by plastic and urgent need for a comprehensive, legally enforceable global framework to address it across entire life cycle of plastic from production to disposal⁴¹ Further Executive Secretary of Intergovernmental negotiating

³⁹ Lucy C Woodall et al, 'The Deep Sea Is a Major Sink for Microplastic Debris' (2014) 51 Royal Society Open Science 1.

⁴⁰ Yanxia Luo et al, 'Effect of Plastic Mulch on Soil Ecosystem and Its Degradation' (2020) 17(1) Environmental Pollution 1.

⁴¹ United Nations Environment Programme, 'Historic Day in the Campaign to Beat Plastic Pollution: Nations Commit to Develop a Legally Binding Agreement' (UNEP, 2 March 2022) <https://www.unep.org/news-and-stories/press-release/historic-day-campaign-beat-plastic-pollution-nations-commit-develop> accessed 11 July 2025.



committee (INC) Secretariat, Jyoti Mathur-Filipp, also stated that without prioritizing reduce and reuse, recycling efforts alone are insufficient and stated that a circular economy reimagines life-cycle of plastics: it seeks to minimize actual production and ensures materials are constantly reused or safely recycled, closing the loop.⁴².

The Circular Economy as a Mitigation Path

The circular economy offers a promising legal and systemic strategy to dismantle this plastic crisis. By prioritising reuse, sharing, repairing, and recycling, we shift away from linear consumption and disposal. Regulatory tools like Extended Producer Responsibility (EPR), plastic taxes, design-for-recycling mandates, and landfill restrictions complement economic incentives. These instruments realign production chains, making waste a resource, not a burden. A true circular economy offers hope: reducing virgin plastic production, designing for reuse, establishing recycling infrastructure, and implementing producer accountability models.⁴³. Closing plastic loops can prevent contamination at source and lower ecological and health risks. However, we must avoid false solutions. Bioplastics and compostable plastics often depend on complex disposal systems and can fragment into microplastics unless properly handled⁴⁴. Without systemic change, recycling merely postpones pollution; incineration exacerbates health crises. Yet circularity is no panacea. Plastic recycling rates remain low around 9% for virgin plastic and recycling sometimes traps hazardous chemicals into new materials.⁴⁵ Ultimately, reducing plastic generation particularly of single-use and chemically unnecessary variants—is essential. A circular framework must encompass design innovation, material substitution, upstream pollution controls, and robust public enforcement.

Plastic Pollution and Legal Journey towards a Circular Economy

Plastic pollution becoming pre-eminent environmental crises of our age pervading oceans, soils and the food chain. Recognizing that a “*produce-use-discard*” model is no longer viable, legislatures and courts across the globe are forging a path towards a circular economy one in which plastics are designed, managed and regulated to remain in productive use while minimizing

⁴² Executive Secretary Jyoti Mathur-Filipp noted at INC-1: “A circular economy for plastics ‘hinges on’ the reduce–reuse–recycle model... If we really cannot recycle, we may need to rethink the model.” Retrieved from UNEP/INC-1 summary

⁴³ MDPI (2021) sustainable development and circular economy policy review.

⁴⁴ Time (‘Dirty Secret of Alternative Plastics’, 2023).

⁴⁵ Centre for International Environment Law (n 1); Jambeck (n 9).



harm. The durability that made plastics revolutionary now condemns them to long-term environmental persistence. The United Nations estimates 11 million tonnes of plastic enter ocean annually, rising to nearly 29 million tonnes by 2040 if unchecked.⁴⁶. Legally, this raises questions around liability and regulatory coverage. In the United States, for instance, cases have explored whether microplastics fall within existing “pollutant” or “solid waste” definitions.⁴⁷. These cases reveal the limitations of current environmental laws in addressing diffuse, persistent pollutants especially those that migrate through air and water. At the international level, treaties such as UNCLOS and MARPOL have been leveraged to regulate marine plastic pollution, though their limitations especially regarding land-based sources are the subject of scholarly critique⁴⁸.

A circular economy shifts focus from disposal to design, reuse and long-term value preservation. The European Court of Auditors aptly observes that product design accounts for roughly 80 per cent of environmental impact over a lifecycle⁴⁹. France’s Loi AGECE (2020) exemplifies this integrated legal strategy: it phases out disposable items (such as plastic tea bags, confetti and cutlery), mandates repairability indices on electronics, and obliges transparency through recyclability logos. Strikingly, it targets every stage—from design to disposal culminating in a goal of zero single-use plastics by 2040⁵⁰. The durability that made plastics revolutionary now condemns them to long-term environmental persistence. The United Nations estimates 11 million tonnes of plastic enter ocean annually, rising to nearly 29 million tonnes by 2040 if unchecked⁵¹. Jyoti Mathur-Filipp (2024) asserted that circular economy is a resource efficient model that eradicates waste as well as pollution, maintains products and resources at their highest value for extended periods, and regenerates natural systems⁵².

Legal and Judicial Measures: A Global Perspective

⁴⁶ Global Plastic Action Partnership, *Unlocking the Plastics Circular Economy: Case Studies on Investment* (2022) 5, 29 Mt/year by 2040; US\$1.2 trillion needed.

⁴⁷ National Academies, *Legal background on microplastic/macroplastic regulations*, summarising US cases.

⁴⁸ M Sujauddin et al, ‘International Legal Systems in Tackling Marine Plastic Pollution’ *Water* 17(10) (2023).

⁴⁹ European Court of Auditors, *Special report 17/2023: Circular economy* (2023).

⁵⁰ France, Loi n° 2020-105 10 Feb 2020 ‘Anti-waste and Circular Economy Law’ (Loi AGECE).

⁵¹ Global Plastic Action Partnership, *Unlocking the Plastics Circular Economy: Case Studies on Investment* (2022) 5, 29 Mt/year by 2040; US\$1.2 trillion needed.

⁵² In a UNEP interview ahead of INC-3, she emphasized transforming a throw-away economy and accelerating talks toward a legally binding treaty by end-2024 Retrieved from UNEP interview



Controlling plastic pollution globally requires voluntary efforts or consumer responsibility as it demands strong legal mandates and active judicial enforcement. Legal frameworks serve as binding commitments that can compel governments, industries, and individuals to reduce plastic usage and improve waste management. Across the world, national laws and international instruments have increasingly been harnessed to regulate the production, distribution, and disposal of plastics. For instance, several countries have implemented complete or partial bans on single-use plastics, recognizing their disproportionately harmful impact on the environment. India's *Plastic Waste Management Rules, 2016* (as amended in 2022), is a case in point, which prohibits specific single-use plastic items and introduces Extended Producer Responsibility (EPR), placing onus on producers and brand owners to manage the post-consumer plastic waste generated by their products⁵³. There is an increasing global agreement on the necessity of a legally binding international convention addressing plastic pollution. In March 2022, UNEA adopted Resolution 5/14 to establish an international legally binding instrument by 2024 aimed at eradicating plastic pollution, notably in marine ecosystems⁵⁴. The proposed treaty aims to cover full lifecycle of plastics from production to disposal as well as considered a landmark development akin to the Paris Agreement on climate change. Such an international legal mechanism, supported by national implementation and enforcement, could standardize regulations and provide financial and technical support to developing countries. The success of this treaty will depend on how comprehensively it addresses source reduction, eco-friendly alternatives, and effective penalties for non-compliance⁵⁵.

Another emerging legal tool is the principle of polluter pays, which holds producers and businesses accountable for environmental damage caused by their products. European Union has adopted directives requiring member states to enforce EPR and reduce packaging waste⁵⁶. Some jurisdictions are also incorporating plastic taxes, encouraging industries to shift to

⁵³ *Plastic Waste Management (Amendment) Rules 2022* (India), <https://egazette.nic.in/WriteReadData/2022/233645.pdf> accessed 14 July 2025.

⁵⁴ United Nations Environment Programme, 'End Plastic Pollution: Towards an International Legally Binding Instrument' (UNEP, 2022) <https://www.unep.org/resources/report/end-plastic-pollution-towards-international-legally-binding-instrument> accessed 11 July 2025.

⁵⁵ Lisa Guppy and Miko Ali, 'The Global Treaty on Plastic Pollution: What Needs to Be in It?' (UNU-INWEH, 2022) <https://inweh.unu.edu/publications/global-plastic-treaty> accessed 14 July 2025.

⁵⁶ European Commission, 'Packaging and Packaging Waste Directive' (Directive 94/62/EC) https://environment.ec.europa.eu/topics/waste-and-recycling/packaging-waste_en accessed 14 July 2025.

biodegradable materials and reducing consumer reliance on disposable plastic items. In Kenya, one of world's strictest anti-plastic laws was introduced in 2017, banning plastic bags and

CONCLUSION

- The observed polarization characteristics of Comet imposing heavy fines and imprisonment for violations⁵⁷. The Kenyan judiciary has upheld this law against several legal challenges, reinforcing the rule of law in environmental governance.
- In India, National Green Tribunal (NGT) has developed as a strong environmental watchdog. In *Krishna Kant Singh v Union of India*⁵⁸, the NGT directed industries to stop illegal plastic burning, citing its detrimental impact on public health and air quality.
- Similarly, in *Almitra H. Patel v Union of India*⁵⁹, Supreme Court addressed the broader issue of solid waste management and emphasized the need to curb plastic waste to protect public health and the environment. These judgments have not only strengthened environmental jurisprudence but also compelled local authorities to adopt stricter compliance measures.
- **Suggestion and Conclusion:**
- Environmental law is wrestling with new responsibilities related to microplastics. Precedents are forming: courts have entertained soil and water remediation cases; air-quality regimes may expand to include plastic particulates; and cross-border marine pollution cases test jurisdiction and enforcement. International agreements, such as the ongoing UN plastics treaty negotiations, promise to harmonise global standards on plastic production caps, pollution liability, and resource stewardship⁶⁰. Plastic pollution transcends environmental degradation it is a public health crisis and a legal challenge. It demands:
- *Policy reform*: Implement production caps, chemical restrictions, Extended Producer Responsibility (EPR) and circular economy mandates.

⁵⁷ Republic of Kenya, *Environmental Management and Co-ordination (Plastic Bags Control and Management) Regulations*, 2017 <https://www.nema.go.ke/images/Docs/Legislation/plastic%20bags%20ban%20gazette.pdf> accessed 10 July 2025.

⁵⁸ *Krishna Kant Singh v Union of India* (2017) Appeal No. 57 of 2017 (National Green Tribunal).

⁵⁹ *Almitra H. Patel v Union of India* (2000) 2 SCC 679 (Supreme Court of India).

⁶⁰ Vox, 'Why is it so hard for the world to act?' (9 Nov 2024) Vox <https://www.vox.com> accessed 11 July 2025.



- *Environmental justice*: Protect vulnerable communities disproportionately affected—from waste-dump neighbours to low-income coastal economies.
- *Scientific standards*: Establish clear metrics for exposure, toxicity and ecological risk to define legal thresholds.
- *Litigation readiness*: Equip legal actors to invoke rights-based and tort frameworks grounded in medical and ecological data.
- *Global cooperation*: Harmonise international treaties on pollutant trade, production, and human-ecological health.

Recycling alone will not eradicate plastic pollution. We must adopt a life cycle approach, necessitating an examination of product design, production, and distribution. Methods that only target one element of economy, such as recycling, fall short of addressing issue. There is dire need systemic change.

There are financial incentives for product reuse, and there is support from high-consuming sectors, primarily enterprises involved in plastic packaging and manufacturing. Existing economic model and its associated policies and incentives prioritize short-term profits while neglecting externalities resulting from economic activity, including resource depletion, environmental degradation, and implications for human health.

The need is to shift economic incentives towards penalizing pollution and rewarding resource efficiency, this will increase economic attractiveness of circular economy solutions.

Three tenets of plastics circular economy-eliminate, innovate, and circulate-offer a fresh outlook on a sustainable future. It implies that we should work to get rid of plastic items that we do not need, develop so that the plastics we do need may be recycled, reused, or composted securely, and recycle whatever we use to keep it out of environment and in economy.

Moreover, a major step forward lies in strengthening international legal frameworks to regulate plastic production and waste. The current legal instruments such as the Basel Convention (amended in 2019 to include plastic waste) have made important strides, yet a dedicated global plastic treaty is necessary. The proposed UN Global Plastic Treaty, currently under negotiation, aims to set legally binding obligations on plastic lifecycle management, including production,



design, and disposal. Such an international treaty can ensure uniform standards and accountability among nations⁶¹.

Governments must also enforce strict domestic legislation targeting single-use plastics. Countries like India have implemented bans on single-use plastics such as cutlery, straws, packaging materials, especially after observing the success of similar bans in countries like Rwanda and Kenya. The effectiveness of such bans depends on rigorous enforcement, public awareness campaigns, and affordable eco-alternatives⁶².

Through integrative legal action combining environmental, occupational, health, and human-rights law with science, community advocacy, and circular-economy principles, we can reduce the tide of plastic pollution. The stakes are clear: safeguarding planetary and human futures depends on urgent, systemic and enforceable change.

Regulations should also impose Extended Producer Responsibility (EPR), compelling manufacturers to manage the post-consumer life of their plastic products. EPR policies implemented in the EU have shown significant success in recycling rates and reduced landfill use⁶³.

Additionally, corporate responsibility and innovation play significant role. Companies must shift towards sustainable packaging, redesigning supply chains to incorporate recyclable or minimal packaging. Many global brands have committed to reducing virgin plastic use and increasing recyclable content by 2025 under voluntary agreements such as Ellen MacArthur Foundation's New Plastics Economy Global Commitment⁶⁴. These voluntary initiatives should be complemented by binding legal obligations to ensure compliance and transparency.

The ocean conservation and clean-up efforts must be scaled up. Technologies such as The Ocean Cleanup Project and fishing-for-litter schemes help remove plastics from marine ecosystems.

⁶¹ Basel Convention on the Control of Trans-boundary Movements of Hazardous Wastes and Their Disposal (adopted 22 March 1989, entered into force 5 May 1992) 1673 UNTS 57; also United Nations Environment Programme, 'Negotiating a Global Plastic Treaty' (UNEP, 2022) <https://www.unep.org/intergovernmental-negotiating-committee-plastic-pollution> accessed 14 July 2025.

⁶² Government of India, Ministry of Environment, Forest and Climate Change, 'Plastic Waste Management (Amendment) Rules, 2021' (12 August 2021); see also Rwandan Ministry of Environment, 'Law No. 17/2019 relating to the prohibition of manufacturing, importation, use and sale of plastic carry bags and single-use plastic items' (2019).

⁶³ European Parliament and Council Directive 2008/98/EC on Waste [2008] OJ L312/3; and also OECD, 'Extended Producer Responsibility' (OECD, 2021) <https://www.oecd.org/environment/waste/extended-producer-responsibility.htm> accessed 10 July 2025.

⁶⁴ Ellen MacArthur Foundation, 'Global Commitment 2023 Progress Report' (2023) <https://ellenmacarthurfoundation.org> accessed 14 July 2025.



Simultaneously, international maritime laws like the MARPOL Convention Annex V, which prohibits discharge of plastics at sea, must be stringently enforced by port and coastal authorities⁶⁵. The cooperation of nations sharing marine borders is essential to track and remove transboundary plastic waste.

In conclusion, addressing plastic pollution globally is a shared responsibility requiring robust legal frameworks, responsible industry practices, scientific innovation, and empowered communities. It is only through a holistic and inclusive approach that the world can effectively combat the plastic crisis and secure a sustainable future for the coming generations.

There are several worldwide initiatives to ban plastics, and 127 nations have passed laws to control the use of plastic bags. Interventions to reduce plastic pollution in marine settings are encouraged by the World Resources Institute. These consist of:

- **Improving wastewater management** is crucial, particularly for the 3 billion individuals lacking access to regulated waste disposal facilities;
- **Improving stormwater management** through implementing filtration systems for stormwater and storm drains and trash collection at river mouths is essential.
- **Adopting green chemistry practices and the development of innovative materials is crucial.** This includes prohibiting difficult-to-manage substances, limiting hazardous chemicals such as phthalates, promoting materials research, and creating new materials that retain the desirable attributes of plastics while eliminating those that cause damage.
- **Practising radical resource efficiency** through the reduction of plastic usage. This includes imposing fees on single-use plastics, encouraging voluntary industry standards to minimize fossil-fuel-based plastics, and shifting cultural norms regarding waste generation, consumption, and reuse.

⁶⁵ International Maritime Organization, 'MARPOL Annex V – Prevention of Pollution by Garbage from Ships' <https://www.imo.org/en/OurWork/Environment/Pages/Garbage-Default.aspx> accessed 14 July 2025.



ECO-FRIENDLY CONTROL OF INSECT PESTS OF STORED GRAINS USING VARIOUS PHYTOEXTRACTS: A REVIEW

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ABSTRACT

Crop plants can be damaged by insect pests, which can lead to reduced quality of food grains and other products. Agriculture is also affected by various pests such as nematodes and invasive weeds, which can decrease crop yield by up to 5% of the world's food production. Stored grain pests can cause a decrease in quality, seed viability, grain weight, and commercial value. While chemical pesticides and insecticides have proven to be effective and cost-efficient, their use can harm the environment by affecting soil fertility, developing resistance to pests through genetic variations, and increasing toxic residues. On the other hand, plant extracts are cost-effective, biodegradable, and eco-friendly. Whether they cannot entirely replace synthetic pesticide production, but they may help to solve problems associated with synthetic pesticide use. In the present review, we discuss stored grain insect pest control by using eco-friendly methods.

KEYWORDS

Stored grain insect pests, Agriculture Weeds, Phytoextracts, Biodegradable, Eco-friendly, etc.

INTRODUCTION

Unwanted plants that are non-native to a particular region are called invasive weeds (IPM, 2014). These species can establish themselves successfully due to their faster reproduction rates, dispersal mechanisms, and ability to quickly adapt and deplete resources, resulting in larger populations in a short period (Dhole, 2013; Ghayal, 2011; Maharajan, 2007). Weeds are considered to be harmful pests in ecosystems and agriculture due to their competition for soil nutrients, space, water, and sunlight. Plants use allelochemicals, also known as eco chemicals, to communicate with each other and protect themselves from herbivores and predators. Unfortunately, pests such as diseases, nematodes, and



invasive weeds can damage agriculture, resulting in lower output and poor-quality grains. This can impact up to 5% of the global food supply (Aneja, 2016). The presence of pests can lead to a reduction in quality, seed viability, and grain weight, ultimately resulting in lower commercial value (Kazmi, 2017).

Coleoptera is a class of insects that primarily affects stored grain pests from various families, including *Sitophilus oryzae* (Curculionidae), *Callosobruchus chinensis* (Bruchidae), *Tribolium castaneum* (Tenebrionidae), and *Trogoderma granarium* (Dermestidae). The rice weevil, also known as *Sitophilus oryzae*, is the most damaging and widespread cereal pest found in tropical warm climatic zones. It mainly infests cereal crops such as wheat, rice, maize, barley, and sorghum (Kazmi, 2017). *Callosobruchus chinensis* is a common species of beetle found in the bean weevil subfamily and is known to be a pest to many stored legumes of chickpea, mung bean, and garden pea. There are various ways to manage pests, but some methods, like spraying and fumigation, can be harmful to insects by entering their body through their cuticle or respiratory system (Thein, 2013). An alternative approach is to use plant derivatives, which can be combined with solid or liquid carriers, such as lacquer, sodium sulfate, or paraffin. This method was suggested by Harding in 1985 as a way to control pests (Soon Il Kim, 2001).

Botanical Insecticide

Azadiracta indica, often known as Neem, was stressed as an efficient botanical insecticide and pesticide by the old conventional method *Vrikshyavurveda* (Das, 2015; Dutta, 2015; Rahman, 2006; Regnault-Roger, 2008). In Indian and Chinese literature, insecticides were made from a variety of medicinal plant sources, including eucalyptus, *Murayya koenegii*, garlic, turmeric, tulsi, cinnamon, and mustard oil. Early on, it was discovered that chemical pesticides and insecticides containing organochlorines, organophosphates, carbamates, and synthetic pyrethroids were more efficient and less expensive than Botanical insecticides (BI). Synthetic insecticides and pesticides have a significant detrimental effect on the ecosystem by reducing soil fertility, causing pest resistance through genetic variety, and raising hazardous wastes (Dutta, 2015). After a few decades, research has concentrated on formulating and standardizing botanical insecticides because of the negative consequences associated with the long-term usage of chemical pesticides. Environmentally friendly formulations called botanical pesticides come from naturally existing elements like germs (viruses, bacteria, fungi), plants, and animals (Aneja, 2016). According to the US-EPA, pesticides made from plants are categorized based on where the active components come from (Mazid, 2011).

1. BT protein known as Plant Incorporated Protectants (PIP)
2. Microorganisms such as bacteria, fungi, and viruses
3. Botanicals utilized as biopesticides include *Azadiracta indica*, also known as neem, *Ipomoea*, *Triphala*, *Pinus kesia*, Limonene, Linalool, Rotenone Pyrethrum and Pyrethrins, *Sabadilla*, and *Ryania*. These pests include aphids, fleas, beetles, and thrips (Mazid, 2011). Since they are less hazardous to animals and degrade quickly, pyrethrins, which are secondary metabolites generated from *Chrysanthemum* flowers, are now a promising class of insecticides. A macrocyclic lactone called abamectin, synthesized by *Streptomyces avermitilis*, is effective against a limited number of pests but has led to Tetranychid mite resistance (Chandeler, 2011). Even for humans, nicotine and rotenone have a significant potential for toxicity and have a similar potency as synthetic chemical pesticides. As a result, improper concentrations like BI might impair the natural (eco-friendly) process of insect management.
4. Insect sex pheromones are a type of biochemical insecticide.

Only a small number of the insecticides included in the 1968 Insecticide Act are generally available for purchase: -

- a) Bioinsecticide: *Bacillus thuringiensis* (BT)
- b) Bioherbicide: *Phytophthora*
- c) Biofungicide: *Trichoderma*
- d) PIP: BT gene, Protease inhibitor, Lectines, Chitinase

According to updated data from a variety of plant and animal sources, 835 active compounds are applied globally. Of these, 680 are synthetic pesticides (82%), 69 are insect pheromones (8%), 61 are plant extracts (7%), and 25 are microorganisms (3%) (Redbond, 2003). The investigation of biopesticides to manage pests in an environmentally friendly manner has been highly advised by the National Farmers Policy, 2007 (Aneja, 2016).

Benefits of utilizing biopesticides

- ✓ Existing natural resource
- ✓ Selective or leaving behind little or no hazardous waste, which makes it less detrimental to the environment and more swiftly decomposes
- ✓ Unique to the target organism.
- ✓ Production is less expensive than chemical pesticides.



- ✓ As part of the Integrated Pest Management program, a tested component property.

The criterion for choosing a botanical pesticide

- ✓ The plant should be everlasting
- ✓ Large biomass and widespread dispersion, i.e., widely available
- ✓ Plants with a variety of applications
- ✓ The plants used should not have a high economic value
- ✓ It is preferable if the active components are active at low concentrations

EXPERIMENTAL LAYOUT

Insecticides produced from plant extracts are widely used across the globe. These extracts are derived from different plant families such as Rutaceae, Lamiaceae, Meliaceae, Asteraceae, Annonaceae, Malvaceae, Piperaceae, Verbenaceae, and Labiatae. The process of deriving partial pure compounds from these extracts involves various methods such as the maceration of fresh leaves and extraction of dried and powdered samples using aqueous-based or polar-non-polar solvents. Soxhlet extraction is a popular extraction method, followed by filtration through Whatman filter paper No. 1. The extracted solution is then subjected to the rotary evaporator to remove excess solvent, resulting in a dark green residue that is stored at 4°C until further analysis. Desired concentrations are achieved by adding alcohol or acetone to the extracted solution. To test the efficacy of the insecticides, Impregnated filter paper dip method is used. Filter papers are dipped in the prepared concentrations for a maximum of 2 minutes, and the solvent is left to air dry. The filter papers are then placed in a Petri dish, and 5-10 pairs of adult insects are released onto the dish. Observations are recorded after 24, 48, 72, 96 hours, and up to 21 days of exposure. Parameters such as contact toxicity and mortality are studied. Similarly, ovipositional or egg-laying parameters are studied by treating grains or seeds with different solvent concentrations, allowing them to air dry, and then placing them in the desired chamber. Data is recorded after the 7th day of oviposition of eggs. Eggs are counted, and grain infestation is observed. Other parameters, such as toxicity, are studied by applying a solution of different concentrations to the thorax (dorsal surface) of pests. The insects are chilled for 10 minutes before applying solutions. Insecticidal activities of specific essential oils are determined by the Fumigation action method. The extract concentrations are applied to filter paper, which is then placed at the bottom of a cup. Weevils are placed in another cup embedded in the first cup and covered with mesh cloth. Polythene mortality is noted after 1, 2, 3, and 4 days of exposure. Permethrin, a synthetic chemical pesticide, is used as a

positive control against treatment. Data collected from 3-4 replicas are subjected to further analytical tests.

Saponins contain plants

a) Properties and structure of the compounds

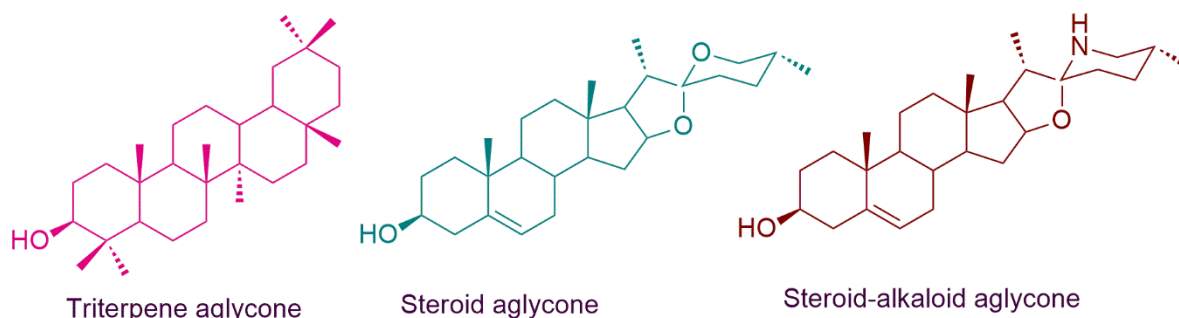


Figure 1. Structure of various substrates of Saponins

Saponins are the glycosides that derive their name from their soap-like properties. They are composed of hydrophilic saccharide chains attached to hydrophobic triterpenic or steroidal structures (aglycone). Saponins are categorized into three main types according to the carbon skeleton of aglycone region: triterpenoidal, steroidal and steroidal-glycoalkaloid saponins (Figure 1). Saponins have a polycyclic ring system in their aglycone or sapogenin structure with either 27 carbon steroid or 30 carbon triterpene (Moses, Papadopoulou, & Osbourn, 2014). The saccharide chain of saponins generally consists of linear oligosides having the length of 2e5 sugar units. The sugar residues include D-glucose, D-mannose, D-fructose, D-xylose, D-galactose, L-arabinose, L-rhamnose, and Dglucuronic acid (Fenwick, Price, Tsukamoto, & Okubo, 1991, pp. 285e327).

Saponins are categorized as monodesmosides (having a single sugar chain linked to C-3 of aglycone) and bidesmosides (having one sugar chains linked to C-3 and second to C-28, C-27, C-26 or C-22 of aglycone). Zanhic acid glycoside (oleanane type triterpenoidal saponin) is categorized as tridesmosidic with three sugar chains linked to aglycone and no free carboxyl group (Oleszek et al., 1992). Monodesmosidic glycosides are more potent in biological activity than bidesmosides or tridesmosides (Jain & Tripathi, 1991; Oleszek et al., 1992). Monodesmosidic saponins with a glycosyl group at C-3 are more bioactive than those having it at C-28. Saponins cannot be classified on the basis of their origin or plant source as there is no correlation between plant species and the saponins they produce. Saponins show detergent-like properties when shaken with water as they form micelles. The linkage between fat-soluble aglycone and water-soluble oligosaccharide chains makes saponin an amphipathic molecule processing surfactant properties leading to the interaction between saponins

and cell membranes. Due to this interaction, saponins show variety of biological effects on living organisms like membrane permeabilising, haemolysis, insecticidal, allelopathic and antifungal activities. Saponins affect food intake, survival, growth rate and reproduction in some insects, fungi, bacteria, viruses, mollusks and animals (Thakur, Melzig, Fuchs, & Weng, 2011).

b) Saponins in plants

Saponins are present in many wild as well as cultivated plant species (Faizal & Geelen, 2013; Moses et al., 2014). The common plants studied for saponins are soapbark, alfalfa, yucca, ginseng, soybean, sugar beet, chickpea and asparagus (Cheok, Salman, & Sulaiman, 2014; Moghimipour & Handali, 2015). Saponins are present in different parts of the plants like leaves, stems, roots, bark and even flowers (Moghimipour & Handali, 2015). More than one type of saponin may occur in the same plant and they also differ in their distribution among different parts depending upon the age of the plant (Kharkwal et al., 2012). Saponin content is very high in some plants and it is greatly influenced by abiotic environmental factors (Moses et al., 2014; Szakiel, Paczkowski, & Henry, 2011). In some plants, saponins are stored in the roots, where they act as phytoprotectant against invading soil-borne microbes that attack plant tissues (Faizal & Geelen, 2013). Triterpenoid saponins are predominant in cultivated crops and steroid saponins are mainly found in plants having health promoting properties (Moses et al., 2014; Tiwari & Singh, 2012). Steroidal saponins accumulate in abundant amounts in alliums, asparagus, fenugreek, yucca, yam and ginseng (Moses et al., 2014). Triterpenoid saponins are common in legumes, chenopods, *Spinacia oleracea* L. (spinach), *Beta vulgaris* L. (sugar beet), *Glycyrrhiza glabra* L. (liquorice), *Helianthus annuus* L. (sunflower), *Aesculus hippocastanum* L. (horse chestnut), *Quillaja saponaria* Molina. (soapbark tree), *Smilax ornata* Lem. (sarsaparilla) and *Camellia sinensis* L. (tea) (Moses et al., 2014; Thakur et al., 2011; Vincken et al., 2007). Sugar beet and quinoa (*Chenopodium quinoa* Willd.) are well known for triterpenoid saponins (De Geyter, Lambert et al., 2007). Steroidal glycosides are primarily found in *Solanum melongena* L. (eggplant or aubergine), *Capsicum* spp. L. (peppers), *Solanum lycopersicum* L. (tomato), *Avena sativa* L. (oats), *Allium sativum* L. (garlic), *Allium cepa* L. (onion), *Allium porrum* L. (leek), *Asparagus officinalis* L. (asparagus), *Dioscorea* spp. L. (yams), *Trigonella foenum-graecum* L. (fenugreek), *Yucca* spp. L. (yucca) and *Panax ginseng* L. (ginseng), whereas steroidal glycoalkaloids are found in solanaceous plants like *Solanum tuberosum* L. (potato) and tomato (Moses et al., 2014; Vincken et al., 2007). Oats contain both triterpenoidal and steroidal glycosides. Alfalfa (*Medicago sativa* L.) is the most studied crop and is

commonly known for glycosidic compounds (De Geyter, Lambert et al., 2007). The common commercial source for triterpenoid Saponins is soapbark tree and for steroid saponins is yucca (Balandrin, 1996; Fenwick et al., 1991, pp. 285e327).

c) General procedure for plant extraction and purification

Saponins occur in the mixture of structurally related forms with similar polarity. Determination of saponins based on gravimetry, foaming properties and haemolytic activity were carried out in early studies (Oleszek, 2002). Saponins are extracted using water alcohol solvent systems. Ethanol is preferred over methanol as solvent for extraction. Ethanol and methanol in combination with water is beneficial for extraction of saponin (Guajardo-Flores García-Patiño, Serna-Guerrero, Gutierrez-Urbe, & Serna-Saldívar, 2012). Methanol at room temperature has been widely used as a solvent for extraction of saponins. Ethanol requires high temperature as an extraction condition and this might decrease the level of saponins by degradation (Ha et al., 2014). Due to huge industrial demand of saponins in food, pharmaceutical and agricultural industries, scientists have formulated new and improved methods of extraction to obtain maximum output. Saponins were extracted using supercritical CO₂ (scCO₂), ethanol, and water as solvents (Bitencourt, Queiroga, Junior, & Cabral, 2014). Microwave (Xu et al., 2012) and ultrasonic assisted (Wu, Lin, & Chau, 2001) extractions were also used for separation of saponins.

Numerous studies have been carried out on extraction, structure elucidation and analysis of saponins from plants. Spectrophotometric and chromatographic techniques used for quantification of saponins from different plant sources were recently reviewed (Cheok et al., 2014). Spectrophotometry is helpful in saponin level estimation and chromatography is utilized in separation and quantification of specific saponins. Thin layer (Oleszek, 2002) and high-performance liquid column chromatography (Elango & Jadhav, 2010; Negi, Negi, Pant, Rawat, & Negi, 2013) were routinely used for purification of saponins. The main problem in HPLC studies is that saponins do not have prominent ultraviolet chromophores required for detection (Oleszek, 2002). In recent studies, estimation of saponins in different plants was carried out by coupling mass spectrometry (MS) with high performance thin layer chromatography (HPTLC) and by using p-anisaldehyde sulphuric acid staining (Reim & Rohn, 2015). It is the fast and reliable method for simultaneous analysis of saponins in plants. For structural studies, Nuclear magnetic resonance (NMR) and Fourier transform infrared (FT-IR) spectroscopy are the commonly employed techniques. NMR spectrum is helpful in determining the sugar linkages in saponin molecules

whereas FT-IR spectrum provides information about functional groups and stereochemistry (Sharma & Paliwal, 2013). The emergence of various new processes and re-evaluation of the existing processing strategies for the extraction of saponins can be used in commercial production. Saponins were successfully extracted and purified from plants like agave (*Agave attenuate* Salm-Dyck.), alfalfa, garlic, ginseng, green cestrum (*Cestrum parqui* L'h_er.), liquorice, soapwort (*Saponaria officinalis* L.) and soapbark tree (Chaieb, 2010).

Pests Control using plant saponins

Saponins directly affect growth and reproduction of insect pests due to their repellent or deterrent activity. They increase mortality levels by lowering food intake and affecting movement of food in the insect gut due to toxicity and less digestibility (Adel et al., 2000). Saponins decrease digestive capabilities by affecting microflora living in the insect gut. They form complexes with the digestive enzymes like proteases and thereby, apparently affect digestion process in the insect gut. Due to their membrane permeabilising ability, saponins rupture the internal lining of mucosal cells in the gut. They also exert strong insecticidal activity by forming complexes with cholesterol, causing cellular toxicity and ecdysial failure in the insects (Taylor et al., 2004). Insects cannot synthesize sterol structures and need cholesterol or phytosterols as precursors from food for the biosynthesis of ecdysteroids. Saponins form indigestible binding with sterols in the food, block uptake of sterols and disturb insect moulting and ecdysis (De Geyter, Lambert et al., 2007).

Many insects refuse to eat saponin containing food and die within few days. Due to their large spectrum of actions and negative influence on the insects, saponins present an excellent model of study to control insect pests. Many researchers have proved the activities of plant-derived saponins against important insect pests like aphids, beetles, weevils, leafhoppers, worms and moths (Table 1). In this section, information available in the literature on insecticidal activity of saponins acting against common insect pests was reviewed.

A) Coleopterans

a) Beetles

Applebaum, Gestetner, and Birk (1965) reported the defensive role of soybean (*Glycine max* L.) saponins against bruchid beetle *Callosobruchus chinensis* L. in stored legume seeds as larvae of beetles does not hydrolyze saponins. Saponins are promising alternatives to synthetic insecticides for protection of seed grains during storage. In earlier studies, Applebaum et al. (1969) discussed saponins



are the important botanical compounds behind the resistance of legumes to a variety of insects. Shany et al. (1970) observed growth-inhibiting activity of lucerne saponins against red flour beetle (*Tribolium castaneum* Herbst), a worldwide pest of stored food products. They noticed that the presence of cholesterol in the insect diet reduces the effect of saponins on beetle growth. Alfalfa saponin inhibits the growth of red flour beetle (Bondi, Birk, & Gestetner, 1973). A study conducted by Pemonge, Pascual-Villalobos, and Regnault-Roger (1997) reported that leaves and seeds of fenugreek have insecticidal properties against red flour beetle. Saponins present in fenugreek seeds cause toxicity to young larvae, decreases fecundity in adults and produces a high degree of mortality. Colorado potato beetle (*Leptinotarsa decemlineata* Say.) causes a great damage to potato crop and reduces its yield because of its ability to acquire resistance to chemical pesticides (Wełgorek, 2005). Waligóra (1998) developed alternative and efficient methods for control of Colorado potato beetles by exploring insecticidal activities of different plant-derived metabolites like glucosinolates, alkaloids and saponins. In their study, Saponins extracted from soapbark tree proved effective for controlling potato beetle. Alfalfa saponins significantly affect growth and survival of Colorado potato beetle. Szczepanik, Krystkowiak, Jurzysta, and Bialy (2001) used potato leaves treated with different concentrations of alfalfa saponins and served them to larvae of Colorado potato beetle. Larvae died after 4e6 days due to non-preference of leaves treated with 0.5% alfalfa saponins. Treatments with lower concentration (0.01e0.001%) also significantly inhibited growth due to low feeding rate. Reduced feed intake, growth rate and survival of Colorado potato beetle on potato leaves containing Saponins was due to less assimilation of saponin-containing food ingested by the beetle. The insecticidal activities of saponins isolated from three alfalfa (*M. Arabica* L., *M. hybrida* Pourr. and *M. murex* Willd.) species were tested by Szczepanik, Bialy, and Jurzysta (2004) against larvae of Colorado potato beetle. Less food intake, reduction in body weight, long lasting larval stage and high mortality rate was observed by using 0.5% alfalfa saponins. Hussein et al (2005) studied insecticidal action of saponin extract from alfalfa roots on hairy rose beetle (*Tropinota squalid*, Col.). Diets containing 750 ppm saponins have decreased progeny of 2nd instars larvae from 51 to 24 per female. Adult emergence rate dropped from 80 (control) to 20% by feeding larvae of control adults on 75 ppm saponins diet for 1 week. Adults fed on alfalfa saponins showed high mortality, reduced fecundity and hatchability. No adult emerged by continuing treatment for 2nd and 3rd larval instars. Soapbark tree saponins restrain feeding and disturb development of Colorado potato beetle by causing toxicity to larvae (Waligóra, 2006). Larvae fed on potato leaves treated with saponins

showed less food consumption and very high mortality. The study proved the possibility of using soapbark tree saponin for protection of potato plants from this pest. The flea beetle utilizes most of the cruciferous plants as natural host but does not infect *B. vulgaris* due to presence of two triterpenoid Saponins (hederagenin cellobioside and oleanolic acid cellobioside) and two other compounds likely to be saponins (Kuzina et al., 2009). Nielsen, Nagao, Okabe, and Shinoda (2010) determined the role of saponins in resistance of *Barbarea vulgaris* R.Br. to the flea beetle (*Phyllotreta nemorum* L.). They compared hederagenin cellobioside and oleanolic acid cellobioside from *B. vulgaris* for feeding deterrent activity and reported hederagenin cellobioside to be a potent feeding deterrents and defensive compound in this plant. Study proved that insecticidal activity of saponin depends on the structure of the aglycone and presence of saccharide chain. Removal of carbohydrate moiety from aglycone (hederagenin and oleanolic acid) resulted in the loss of bioactivity.

b) Weevils

Weevils are the major pest of stored food grains and are commonly found in dry foods including nuts, seeds, cereals and grain products (Sarwar, 2015). Many studies have reported use of saponins for stored product protection against weevils. Pemonge et al. (1997) investigated insecticidal activity of fenugreek seeds on bean weevil (*Acanthoscelides obtectus* Say.). Topical applications of leaf (30 mg/insect) and seed (6 mg/insect) extract produced mortality and decreased female fecundity within two days in bean weevil. Use of fenugreek seed powder in common bean (*Phaseolus vulgaris* L.) during storage has caused rapid adult mortality and inhibited larval development. There was significant decrease in adult emergence compared to untreated stored bean samples. Fenugreek leaves and seeds contain steroidal saponin (diosgenin) and it produces insecticidal effects. Cowpea seed weevil (*Callosobruchus maculatus* Fabricius.) is a serious insect pest of important legume seeds like cowpea, mungbean, and pigeon pea during storage. A cowpea weevil attack reduces seed quality and affects germination and they can destroy seeds completely within a few months of storage. Mazahery-Laghab (1997) investigated the effect of saponin from alfalfa shoot and root tissues on cowpea seed weevil. They placed diet pellets of crude saponin extract from shoots and roots (100, 10 and 1%) in jars containing infested cowpea seeds. The study reported delay in development and larval mortality of cowpea weevil. Diet pellets incorporating 100% shoot Saponins proved very effective with 100% insect mortality. The rice weevil (*Sitophilus oryzae* L.) feed on whole seeds and flour of rice, wheat and maize and is a serious stored product pest of cereals. Obeng-Ofori and Akuamoah (2000) assessed toxicity of



the mahogany tree (*Khaya senegalensis* Desr.) and siam weed (*Chromolaena odorata* L.) leaf extracts against rice weevil. The siam weed was moderately toxic and mahogany tree was highly toxic to rice weevil. A high dose of mahogany tree leaf extract completely inhibited progeny production by rice weevil. Phytochemical screening has confirmed the presence of saponins in siamweed and mahogany leaf extracts. Field pea (*Pisum sativum* L.) and soyabean flour have insecticidal activity against weevils. Taylor et al. (2004) reported triterpenoid saponin responsible for feeding deterrence activities of pea and soybean flour extracts against rice weevil. They identified dehydrosoyasaponin I as an active feeding deterrent compound against rice weevil. Lysolecithins were inactive against rice weevils whereas mixture of dehydrosoyasaponin I and lysolecithins enhanced insecticidal effects of dehydrosoyasaponin I in this study. Bisdesmosidic saponin (Securidacaside A) of *Securidaca longepedunculata* (violet tree) have shown deterrence and toxicity to *Sitophilus zeamais* (maize weevil) and *Callosobruchus maculatus* (cowpea weevil) (Stevenson et al., 2009). The study reported approximately 80 and 50% reduction of maize and cowpea weevil emergence, respectively, by using dry root bark powder and the activity proved effective up to 9 months of grain storage. Flour from barrel medic (*Medicago truncatula* Gaertn.) seeds also contains specific saponins with a toxic effect on rice weevil. Da Silva et al. (2012) purified and identified this compound as 3-GlcA-28-AraRhaXyl-medicagenate responsible for inducing mortality only in rice weevil and not in the other tested insect species.

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AUTHORSHIP PATTERN AND DEGREE OF COLLABORATION IN GOODS AND SERVICES TAX (GST)

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ABSTRACT

The objective of this study is to analyze the research papers on Goods and Services Tax (GST) available in 2011-2015 from JSTOR and the period of 2011-2015. The study also analyzed the year-wise distribution of publications, Degree of collaboration, Source of Published Journals, Language wise distribution and average references contribution of Publications.

KEYWORDS

Goods and Services Tax (GST), Bibliometrics, Bibliometric Analysis, Degree of collaboration.

INTRODUCTION

It is an important research tools for understanding the subjects it aims at measuring the utility of documents and relationships between documents and fields. The present study Literature on Goods and Srvices Tax (GST): A Bibliometrics Analysis is based on 2011-2015 Publications of JSTOR (N-LIST) during 2011-2015. The article on Goods and Services Tax (GST) in 2011-2015 is taken into consideration.

LITERATURE REVIEW

The number of authors contributing to scholarly publications in terms of authorship pattern is an instructing part of any bibliometric study. A count of number of authors contributing to publications offers some indication to degree of collaboration between authors. Cronin (2001) comment, authorship as” undisputed coin of the real in academic “and” absolutely central to the academic reward system”.However, the concept of authorship wads evolved over the course of the 20th century, with a steady increase in collaboration. This trend was anticipated by Price (1963), who stated, “by 1980 the single author paper will be extinct” and scholarly publication will” more steadily toward infinity of author per paper”. Collaboration research refers to a research in which any research project is being carried out by at least two people by engaging their efforts in mind and body. It is very common in the field of sciences as compare to humanities. As part of literature search, the author found various



studies in different disciplines based on the authorship pattern and collaborative research. Some of the literatures are reviewed by the authors before conducting the current study. By observing the *Chemical Abstract* for the period of 1910-1960, Price (1963) was among the first to study the authorship pattern and opined that multi authored papers are gradually increasing with simultaneous reduction in single-authored papers.

Farahat (2002) examined the patterns of authorship in nineteen Egyptian journals of agricultural science and found that multiple- authorship was predominant and co-authored papers were accounted as 79% of the sample. Cronin, Shaw and Berre (2003) observed the co authorship and sub authorship collaboration in the scholarly journal literature of psychology and Philosophy as manifested in the 20th century and highlighted the rates of co authorship and importance of collaboration. They found that among a total of 2,707 publications of 2001, (74%) are single authored.

GOODS AND SERVICES TAX (GST):

Goods and Services Tax is an Indian tax system that imposes various types of taxes on the production process. Goods and Services Tax is a tax that unifies all tax processes in India. (Khedekar, 2025)

On July 1, 2017, India implemented the Goods and Services Tax (GST), an indirect tax regime. It is a destination-based tax which means that the place where the products or services are purchased is responsible for collecting the tax. Under the GST system, companies with annual revenue of more than ₹20 lakh (₹10 lakh for the North Eastern states) are required to register and comply with the GST rules. Since GST is a multi-stage tax system, tax is paid at each supply chain link from the manufacturer to the buyer. However, only the final consumer will be liable for paying the tax. Establishing a consistent tax structure across the country and eliminating multiple taxes, improved efficiency in tax collection and compliance. (Bharti Stock Market, 2025).

BIBLIOMETRICS:

In 1969, Pritchard used the term 'bibliometrics' in his article 'Statistical Bibliography or Bibliometrics' published in the Journal of Documentation, and it was known as statistical bibliography. The word 'biblio' comes from a combination of the Latin and Greek words 'biblion'. It was a form of the word biblion which is equivalent to the word byblo (os) meaning book, paper which comes from the word Byblos, a city in Phoenicia famous for its paper export trade. On the other hand, the word metrics refers only to the science of measurement and comes from the Latin or Greek words metricus or metrics, respectively, each meaning measurement. Pritchard explained the term as 'the metrology of



information transfer processes' and said that its aim is the analysis and control of processes. The British Standards Institution defines bibliometrics as 'the study of documents and publication patterns to which mathematical and statistical methods have been applied'. (Pritchard, 1969).

Bibliometrics as "a field of inquiry devoted to the quantitative analysis of science and scientific fields". (Merton and Garfield, 1963)

Pritchard defined it as "the application of mathematical and statistical methods to books and other media of communication". He also defined it as "the measurement of the process of information transfer and its purpose is to analyze and control the process". (Pritchard, 1969).

The term as "the quantitative treatment of the properties of recorded discourse and the behavior associated with it". (Fairthorne, 1969).

Bibliometrics as "the study of documents and publication patterns to which mathematical and statistical methods have been applied". This is essentially the same as Pritchard's definition. (The British Standard Glossary of Documentation Terms, 1976).

Bibliometrics as "the quantitative analysis of the bibliographic characteristics of a body of literature". (Hawkins, 1977).

Bibliography titled Bibliography stated that "bibliography provides information about the structure of knowledge and how it is communicated". (Nicholas and Ritchie, 1978).

The term as "the study and measurement of all forms of written communication and their authors". (Potter, 1981),

The term informationalism to encompass almost all aspects of bibliography and bibliography. (Morales, (1985). "Bibliography is the quantitative study of physical published units or bibliographic units or representatives of either." (Broadus, 1987).

Bibliography as "the organization, classification, and quantitative evaluation of all macro and micro forms of communication - including their authorship through mathematical and statistical calculus". (Sengupta, 1990).

BIBLIOMETRIC ANALYSIS

Bibliometric analysis is a statistical analysis of written publications, frequently employed to conduct a quantitative analysis of academic literature (Chen et al., 2016).

This method can be defined as a discipline concerned with the measurement of communication and information as expressed in any type of document and across all fields of activity (Martín-Martín et al., 2018).

Bibliometric analysis has gained immense popularity in business research in recent years and its popularity can be attributed to (1) the advancement, availability, and accessibility of bibliometric software such as Gephi, Leximancer, VOSviewer, and scientific databases such as Scopus and Web of Science, and (2) the Cross-disciplinary pollination of the bibliometric methodology from information science to business research. More importantly, the popularity of bibliometric analysis in business research is not a fad but rather a reflection of its utility for (1) handling large volumes of scientific data, and (2) producing high research impact. (Donthu et al., 2020, Donthu, Kumar, Pattnaik, & Lim, 2021, Khan et al., 2021),

Scholars use bibliometric analysis for a variety of reasons, such as to uncover emerging trends in article and journal performance, collaboration patterns, and research constituents, and to explore the intellectual structure of a specific domain in the extant literature (Donthu et al., 2021, Verma and Gustafsson, 2020, Donthu et al., 2020).

OBJECTIVE OF THE STUDY

The objectives of the present study are:

1. To identify Year Wise Distribution of Publications
2. To analyse Authorship Pattern.
3. To analyse the Year Wise Distribution of Bibliographical Sources.
4. To determine degree of collaboration.
5. To analyse the Year Wise Distribution for Length of Publications.
6. To analyse Average number of References Per Publications.

METHODOLOGY

Methodology means study of method or A. system of methods and rule applicant to research or work. It is connected basically with what principles and technique to be follow for collecting data information and material for a given research project. (Kothari, 1990).

For the present study quantitative research method is used.

SCOPE AND LIMITATION OF THE STUDY

The present study is based on 2011-2015 publications of the JSTOR (N-LIST) during 2011-2015. The present study is based on over all 25687 publications appended in JSTOR on Goods and Services Tax (GST) during 5 years i.e. 2011-2015.

DATA COLLECTION

The term data refers to qualitative or quantitative attributes of a variable or set of variables. The data was collected from 2011-2015 Publications of 'JSTOR (N-LIST)' on the subject Goods and Services Tax (GST) during 2011-2015 appended to 2011-2015 publications which were further analysed.

DATA ANALYSIS

Analysis of the data is essential part of any study. Data analysis is done for the purpose of huge volume of data is reduced into meaning full case report. Analysis of total 2011-2015 publications Goods and Services Tax (GST) covered under JSTOR during 2011-2015. It was done by using various parameters like to identify the core journals; ranking of journal, ranking of another, to find out subject wise distribution of journals, to find out Year wise distribution, to find out form wise, country wise distribution. The data was analyzed and presented in the form of tables and graphs to show the result prominently.

ANALYSIS AND RESULTS

According to the objective of the study, analysis and findings of the study are outline below.

1. Year- Wise Distribution of Publications

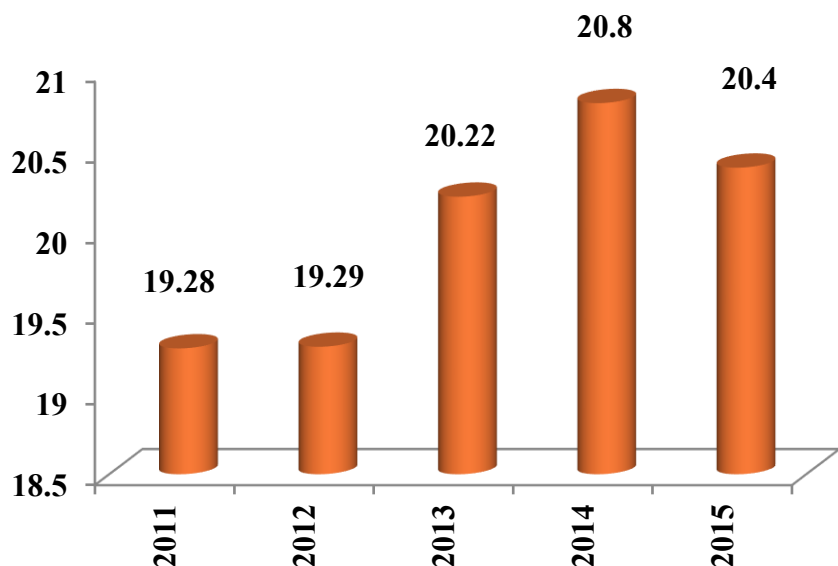
Table No. 1. Year- Wise Distribution of Publications

The year-wise distribution of publication is shown in Table No.1.

Year	Publication	Percentage %	Cum.%
2011	4953	19.28	19.28
2012	4956	19.29	38.57
2013	5195	20.22	58.79
2014	5342	20.8	79.6
2015	5241	20.4	100
Total	25687	100	

Table No.1. presents the year-wise distribution of publications during the period 2011-2015, along with their percentage share and cumulative percentage. A total of 25,687 publications were produced during the study period. Among these, 4,953 publications (19.28%) were published in 2011, accounting for the lowest share of the total output. In 2012, the number of publications increased slightly to 4,956 (19.29%), bringing the cumulative percentage to 38.57%.

**Fig. No. 1. Year- Wise
Distribution of Publications**



2. Authorship Pattern

Table No. 2. Authorship Pattern

year	1 Authors publications	2 Authors publications	3 Authors publications	4 Authors publications	More Than Four Authors publications	Author Name not mention	TOTAL
2011	1158	1275	1090	972	423	35	4953
2012	1205	1130	1150	906	512	53	4956
2013	1199	1230	1219	924	598	25	5195
2014	1361	1140	1250	955	601	35	5342
2015	1302	1122	1015	977	798	27	5241
Total	6225	5897	5724	4734	2932	175	25687

Table No.2. presents the distribution of publications according to the number of authors involved during the period 2011-2015. A total of 25,687 publications were published during the study period. Among the various authorship categories, single-authored publications accounted for the highest number with 6,225 papers (24.23%), indicating that individual research contributions remained significant. Publications with two authors constituted 5,897 papers (22.96%), followed closely by three-authored publications with 5,724 papers (22.28%). The category of four-authored publications contributed 4,734 papers (18.43%), while publications with more than four authors accounted for 2,932 papers (11.42%). A small number of records (175 publications; 0.68%) did not mention the author names. Year-wise

analysis reveals that single-authored publications increased from 1,158 papers in 2011 to 1,361 papers in 2014, before declining slightly to 1,302 papers in 2015. Publications involving two, three, and four authors remained relatively stable throughout the study period. Notably, publications with more than four authors showed a steady increase from 423 papers in 2011 to 798 papers in 2015, indicating growing research collaboration and team-based scholarly work.

3. Year- wise Distribution of Bibliographical Sources

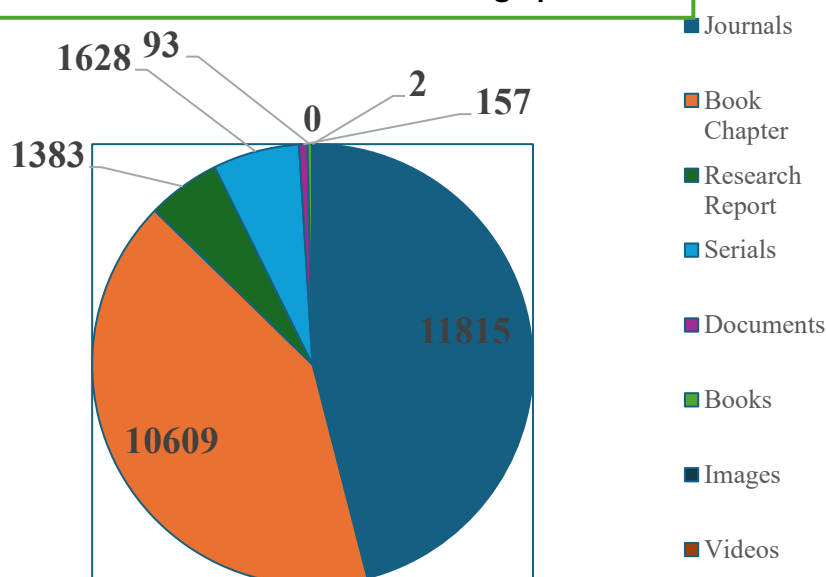
Table No. 3 Year- wise Distribution of Bibliographical Sources

Year	Journals	Book Chapters	Research Report	Serials	Documents	Books	Images	Videos	Total
2011	2360	2063	193	283	25	29	0	0	4953
2012	2297	2094	229	281	35	20	0	0	4956
2013	2350	2306	278	201	41	17	2	0	5195
2014	2424	2120	318	434	34	12	0	0	5342
2015	2384	2026	365	429	22	15	0	0	5241
Total	11815	10609	1383	1628	157	93	2	0	25687

Table No. 3. shows the distribution of publications by document type during the period 2011-2015. A total of 25,687 publications were identified and classified into journals, book chapters, research reports, serials, documents, books, images, and videos. Among all document types, journal articles constituted the largest share with 11,815 publications (45.99%), indicating that journals were the most preferred medium for scholarly communication. Book chapters ranked second with 10,609 publications (41.30%), reflecting a substantial contribution of edited books and conference proceedings to the overall research output. Research reports accounted for 1,383 publications (5.38%), while serials contributed 1,628 publications (6.34%). The number of publications categorized as documents was relatively small, with 157 records (0.61%), and only 93 books (0.36%) were published during the study period. A negligible number of images (2 records; 0.01%) were identified, whereas no video publications were recorded. Year-wise analysis shows that journal publications remained consistently high, ranging from 2,297 publications in 2012 to 2,424 publications in 2014. Book chapters also maintained a strong presence throughout the study period, reaching a peak of 2,306 publications in 2013. Research reports exhibited steady growth from 193 publications in 2011 to 365 publications in

2015, suggesting increasing emphasis on project-based and institutional research outputs. Similarly, serial publications increased considerably in 2014 and 2015.

Fig.No. 3 Year- wise Distribution of Bibliographical



4. Degree of Collaboration

The Degree of Collaboration (DC) was calculated using Subramanyam's formula:

$$DC = \frac{N_m}{N_m + N_s}$$

where:

N_m = Number of multi-authored publications

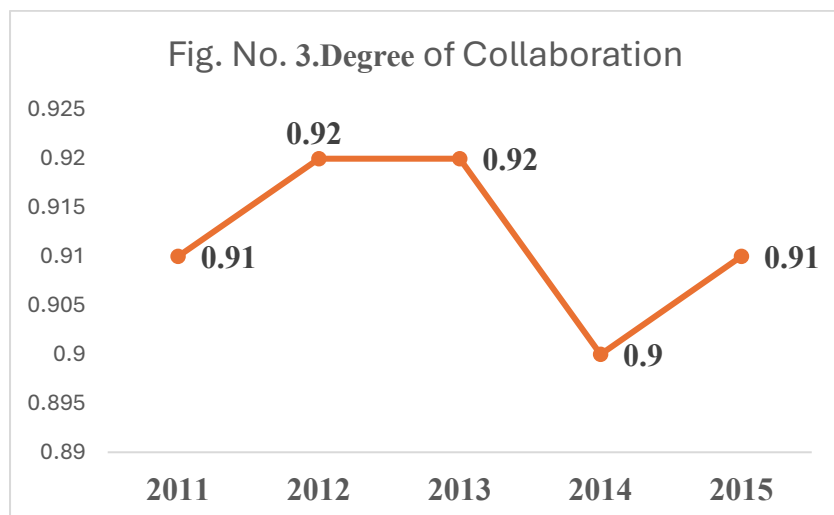
N_s = Number of single-authored publications

Table No.4. Degree of Collaboration

Year	Single Author (Ns)	Multiple	Total (Nm+Ns)	Degree of Collaboration
2011	1158	12980	14138	0.91
2012	1205	13841	15046	0.92
2013	1199	13894	15093	0.92
2014	1361	13576	14937	0.9
2015	1302	13526	14828	0.91
Total	6225	67817	74042	0.91

Table No.4.Presented degree of collaboration for the entire study period was 0.916, which means that approximately 91.6% of the total publications were authored by two or more researchers, while only

8.4% were single-authored. This demonstrates a strong collaborative research culture and highlights the importance of teamwork, knowledge sharing, and interdisciplinary cooperation in the field under study.



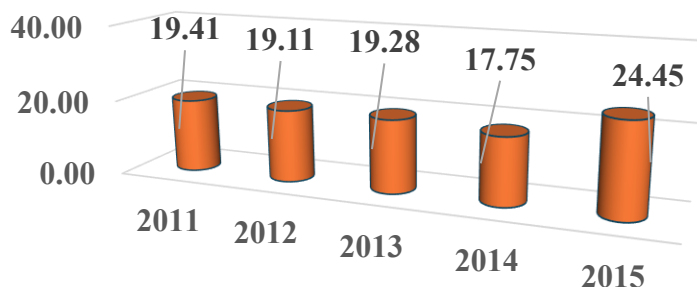
5. Year- Wise Distribution of Length of Publication

Table No.5. Year- Wise Distribution of Length of Publication

Year	No. of Articles	No. of Pages	Percentage %	Cum.%
2011	4953	25868	19.41	19.41
2012	4956	25468	19.11	38.52
2013	5195	25698	19.28	57.8
2014	5342	23654	17.75	75.55
2015	5241	32589	24.45	100
Total	25687	133277	100	

Table No.5. presents the year-wise distribution of articles and the corresponding number of pages published during the period 2011-2015. A total of 25,687 articles comprising 133,277 pages were published during the study period. The highest page output was observed in 2015, with 5,241 articles contributing 32,589 pages, which accounted for 24.45% of the total pages published during the study period. This brought the cumulative percentage to 100%.

Fig. No. 4. Year- Wise Distribution of Length of Publication



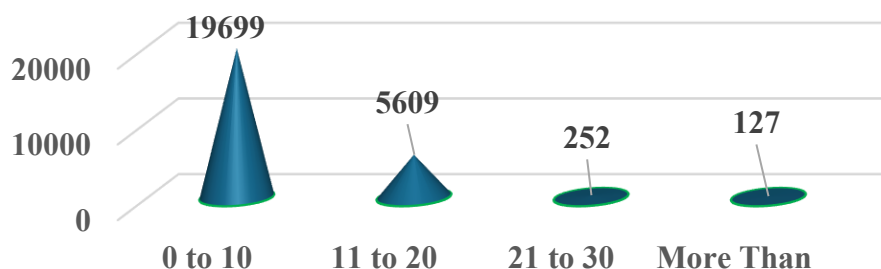
6. Year- Wise Distribution of Average References Per Publication

Table No. 6. Year- Wise Distribution of Average References Per Publication

Year	0 to 10	11 to 20	21 to 30	More Than	Total
2011	3817	1063	48	25	4953
2012	3777	1094	50	35	4956
2013	3816	1306	58	15	5195
2014	4146	1120	48	28	5342
2015	4143	1026	48	24	5241
Total	19699	5609	252	127	25687

Table No. 6. presents the distribution of articles according to their page length during the period 2011-2015. The articles have been categorized into four groups: 0–10 pages, 11–20 pages, 21–30 pages, and more than 30 pages. A total of 25,687 articles were published during the study period. Among these, 19,699 articles (76.69%) were within the 0–10 page range, making it the most dominant category. Articles with 11–20 pages numbered 5,609 (21.84%), while 252 articles (0.98%) fell within the 21–30-page category. Only 127 articles (0.49%) exceeded 30 pages in length.

Fig. No. 5. Year- Wise Distribution of Average References
Per Publication



CONCLUSION

The present study analysed a total 25687 publications in JSTOR from 2011-2015. The analysis shows that the year-wise distribution shows the Publications has been extended from 2011-2015. Length wise distribution of publications. The degree of collaborations is. 0.94. The number of pages has also been increased. Overall, seeing the increasing impact Goods and Services Tax (GST), the most research papers are published in 2022. Also, the most published research papers in Indian journals are published in India.

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ROLE OF HUMIC ACID AND NAPHTHALENE ACETIC ACID IN ENHANCING SEED GERMINATION AND SEEDLING VIGOUR OF GREEN GRAM (*VIGNA RADIATA* L.): A REVIEW

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ABSTRACT

Green gram (*Vigna radiata* L. Wilczek), commonly known as mung bean, is an important pulse crop valued for its high protein content, short growth duration, and adaptability to diverse agro-climatic conditions. Successful crop establishment depends largely on rapid and uniform seed germination, which influences seedling vigour and final yield. Seed priming with plant growth regulators and bio stimulants has emerged as an effective approach to enhance germination and early seedling growth. Among these, humic acid and Naphthalene Acetic Acid (NAA) are widely used due to their ability to regulate physiological and biochemical processes associated with seed development.

This review evaluates the effects of humic acid and NAA on germination and seedling growth of green gram, incorporating experimental findings obtained during the Kharif season of 2023 along with recent scientific literature. The results demonstrated that seed soaking with humic acid significantly improved germination and seedling vigour. The treatment of humic acid at 150 ppm recorded the highest germination percentage (90.25%) and seedling vigour index (2908.93), while humic acid at 100 ppm produced maximum shoot length (25.30 cm) and root length (10.30 cm). In contrast, higher concentrations of NAA reduced germination and seedling growth, although NAA at 45 ppm resulted in the highest root-to-shoot ratio (0.84). Overall, humic acid treatments proved more effective than NAA in promoting seedling establishment and growth.

Recent studies have further confirmed that humic substances enhance nutrient uptake, stimulate enzymatic activity, improve root development, and increase tolerance to environmental stress. These benefits contribute to improved crop establishment and productivity. Therefore, humic acid can be considered an eco-friendly and cost-effective seed priming agent for improving seed quality and early seedling performance in green gram cultivation.



KEYWORDS

Green gram, Seed priming, Humic acid, Naphthalene acetic Acid, Germination, Seedling vigour, Plant growth regulators.

INTRODUCTION

Green gram (*Vigna radiata* L. Wilczek), commonly known as mung bean, is one of the most important pulse crops cultivated in tropical and subtropical regions of the world. It is highly valued for its short growth duration, wide adaptability, and excellent nutritional composition. The seeds contain approximately 24–26% protein, 60–65% carbohydrates, and appreciable amounts of vitamins and minerals, making green gram an important component of human nutrition, particularly in vegetarian diets (Kumar and Pratap, 2021). In addition to its nutritional importance, the crop contributes to sustainable agriculture through its ability to fix atmospheric nitrogen in association with *Rhizobium* bacteria, thereby improving soil fertility and reducing dependence on synthetic fertilizers (Singh et al., 2022).

India is the largest producer and consumer of green gram and accounts for a major share of the global cultivated area and production. The crop is predominantly grown in Maharashtra, Rajasthan, Madhya Pradesh, Gujarat, Karnataka, Andhra Pradesh, Bihar, and Uttar Pradesh under diverse agro-climatic conditions. According to recent agricultural statistics, green gram occupies approximately 3.7 million hectares with an annual production exceeding 1.7 million tonnes, highlighting its significance in the pulse production system of the country (Directorate of Economics and Statistics, Government of India, 2023). Owing to its short duration and adaptability, green gram is often incorporated into multiple cropping systems and serves as an important crop for enhancing farm income and soil health.

The success of green gram cultivation largely depends on rapid and uniform seed germination, which determines seedling establishment, plant population, and ultimately crop productivity. However, factors such as low seed vigour, moisture stress, temperature fluctuations, salinity, and nutrient deficiencies often impair germination and seedling growth, resulting in poor crop stands and reduced yields (Basma et al., 2019). Therefore, improving seed quality and early seedling development remains an important objective in pulse crop production.

Seed priming has emerged as an effective and economical technique for enhancing seed performance under both normal and stressful environmental conditions. The process involves controlled hydration of seeds before sowing, allowing pre-germinative metabolic activities to occur without actual radicle

emergence. Primed seeds generally exhibit faster germination, improved seedling vigour, greater stress tolerance, and enhanced field emergence compared with untreated seeds (Paparella et al., 2015). Numerous studies have demonstrated that seed priming improves enzymatic activities, membrane integrity, nutrient mobilization, and antioxidant defense mechanisms, leading to better crop establishment and growth (Farooq et al., 2019).

Among the different seed priming agents, humic acid and auxin-based plant growth regulators such as Naphthalene Acetic Acid (NAA) have attracted considerable attention because of their beneficial effects on plant growth and development. Humic acid, a major component of soil organic matter, acts as a natural biostimulant by enhancing nutrient uptake, stimulating root proliferation, increasing chlorophyll synthesis, and improving plant tolerance to environmental stresses (Canellas et al., 2023). It also promotes microbial activity and improves soil physical properties, thereby creating favourable conditions for seedling growth and development.

Naphthalene Acetic Acid (NAA), a synthetic auxin, is widely used in agriculture for regulating various physiological processes, including cell division, cell elongation, root initiation, and vascular differentiation. Appropriate concentrations of NAA can stimulate root growth and improve seedling establishment; however, excessive concentrations may adversely affect germination and seedling development due to hormonal imbalance (Taiz et al., 2018). Understanding the comparative effects of humic acid and NAA on germination behaviour and seedling growth is therefore essential for developing efficient seed enhancement strategies in green gram. Such information can contribute to improved crop establishment, higher productivity, and sustainable pulse production under changing environmental conditions.

IMPORTANCE OF SEED PRIMING IN PULSE CROPS

Seed priming is a pre-sowing seed treatment technique involving controlled hydration that initiates early metabolic activities necessary for germination without allowing radicle protrusion. This approach enhances physiological and biochemical processes within the seed, resulting in improved germination performance and seedling establishment (Paparella et al., 2015). Primed seeds generally exhibit faster and more synchronized germination, enhanced seedling vigour, efficient nutrient mobilization, greater tolerance to environmental stresses, and improved field emergence (Farooq et al., 2019).

In pulse crops, seed priming has been widely recognized as an effective strategy for improving germination percentage, seedling growth, root development, biomass production, and yield potential.

The beneficial effects of priming are associated with increased activities of hydrolytic enzymes, enhanced reserve mobilization, improved membrane integrity, and activation of antioxidant defense systems that protect seedlings from oxidative damage during germination (Ashraf and Foolad, 2005; Paparella et al., 2015). Studies in mung bean, chickpea, lentil, and pigeon pea have demonstrated that seed priming contributes significantly to rapid seedling establishment and improved crop performance under both normal and stress conditions (Farooq et al., 2019).

HUMIC ACID AS A BIOSTIMULANT

Humic acid is a major component of humic substances formed through the decomposition and humification of plant and microbial residues in soil. It is rich in biologically active functional groups, including carboxyl, phenolic hydroxyl, and quinone groups, which contribute to its growth-promoting properties (Nardi et al., 2022). In recent years, humic acid has gained importance as a natural bio stimulant because of its positive effects on plant growth, nutrient utilization, and stress tolerance.

3.1 Mechanism of Action

Humic acid influences plant growth through several physiological and biochemical mechanisms:

- Enhances nutrient availability and uptake by increasing membrane permeability and root absorption capacity.
- Stimulates root cell division, elongation, and lateral root formation.
- Increases chlorophyll synthesis and photosynthetic efficiency.
- Activates respiratory and metabolic enzymes involved in plant growth.
- Improves water retention capacity and tolerance to abiotic stresses such as drought and salinity.

Recent studies have shown that humic substances exhibit hormone-like activities, particularly auxin-like effects, which regulate gene expression associated with root development, nutrient transport, and stress adaptation (Canellas et al., 2023; Nardi et al., 2022). Furthermore, humic acid promotes microbial activity in the rhizosphere, leading to enhanced nutrient cycling and improved plant growth (Rouphael and Colla, 2024).

3.2 Effect on Germination and Seedling Growth

The experimental findings revealed significant improvements in germination and seedling vigour following humic acid treatments in green gram. Among all treatments, humic acid at 150 ppm recorded the highest germination percentage (90.25%) and seedling vigour index (2908.93), indicating that

moderate concentrations provide optimal physiological stimulation for seed germination and early seedling growth.

Previous studies have reported similar responses in legumes such as mung bean, soybean, chickpea, and lentil, where humic acid enhanced germination, root development, nutrient uptake, and seedling biomass accumulation (Canellas et al., 2023; Nardi et al., 2022). The positive effect of humic acid is attributed to improved metabolic activity, enhanced nutrient mobilization, and stimulation of plant hormone-like responses during germination.

The present investigation further demonstrated that humic acid at 100 ppm produced the highest shoot length (25.30 cm) and root length (10.30 cm), suggesting that humic acid promotes balanced vegetative growth and vigorous seedling establishment.

NAPHTHALENE ACETIC ACID (NAA) AND SEEDLING DEVELOPMENT

Naphthalene Acetic Acid (NAA) is a synthetic auxin widely used in agriculture to regulate plant growth and developmental processes. Auxins are essential plant hormones that control cell division, elongation, differentiation, root initiation, and vascular tissue development (Taiz et al., 2018). NAA is commonly applied to improve rooting, fruit retention, and vegetative growth in several crops.

4.1 Physiological Functions

NAA exerts its effects through multiple physiological mechanisms:

- Promotes cell elongation and expansion.
- Stimulates root initiation and root development.
- Enhances mobilization of stored food reserves.
- Regulates hormonal signalling pathways involved in plant growth and differentiation.

Although low concentrations of NAA can promote growth, excessive levels may inhibit seed germination and seedling development due to hormonal imbalance, altered metabolic activities, and phytotoxic effects (Davies, 2010).

4.2 Response of Green Gram Seeds to NAA

The results of the present study indicated that increasing concentrations of NAA progressively reduced germination percentage and seedling vigour in green gram. The lowest germination percentage (52.50%) and seedling vigour index (566.95) were observed at 45 ppm NAA. These findings suggest that higher concentrations of NAA may adversely affect germination processes and seedling growth.

However, NAA treatments significantly increased the root-to-shoot ratio. The highest root-to-shoot ratio (0.84) was recorded at 45 ppm NAA, indicating preferential stimulation of root growth relative to shoot growth. Similar observations have been reported in several legume crops where auxin application enhanced root initiation while suppressing shoot elongation at higher concentrations (Davies, 2010; Taiz et al., 2018). Such responses are generally attributed to auxin-mediated regulation of cell division and elongation within root tissues.

COMPARATIVE ASSESSMENT OF HUMIC ACID AND NAA

The comparative evaluation of humic acid and NAA treatments clearly demonstrates the superior effectiveness of humic acid in enhancing germination and seedling vigour in green gram. While humic acid improved all major growth parameters, higher concentrations of NAA negatively affected germination and seedling development.

Parameter	Best Treatment
Germination Percentage	Humic Acid 150 ppm
Seedling Vigour Index	Humic Acid 150 ppm
Shoot Length	Humic Acid 100 ppm
Root Length	Humic Acid 100 ppm
Root-to-Shoot Ratio	NAA 45 ppm

Humic acid promoted balanced root and shoot growth, resulting in improved seedling vigour and establishment. Its positive effects are linked to enhanced nutrient uptake, increased enzyme activity, hormone-like stimulation, and improved physiological efficiency (Canellas et al., 2023). In contrast, NAA primarily influenced root growth patterns and root-to-shoot ratio but reduced overall seedling performance at higher concentrations. Therefore, based on the present findings and supporting literature, humic acid can be considered a more effective and environmentally sustainable seed priming agent for improving germination and early seedling growth in green gram.

FUTURE PROSPECTS

The increasing demand for sustainable and environmentally friendly agricultural practices has highlighted the importance of bio stimulants such as humic acid in crop production. Although numerous studies have demonstrated the positive effects of humic acid on seed germination, seedling



vigour, nutrient uptake, and stress tolerance, further research is required to maximize its potential in pulse crop cultivation.

One promising area of investigation is the combined application of humic acid with beneficial microorganisms, including *Rhizobium*, *Azotobacter*, *Azospirillum*, phosphate-solubilizing bacteria (PSB), and arbuscular mycorrhizal fungi (AMF). Such integrated approaches may enhance biological nitrogen fixation, nutrient availability, root development, and plant resilience under adverse environmental conditions. Synergistic interactions between humic substances and plant growth-promoting microorganisms have been reported to improve nutrient-use efficiency and overall crop performance (Canellas et al., 2015; Nardi et al., 2022).

Further field-level validation is necessary to evaluate the effectiveness of humic acid treatments across different agro-climatic regions, soil types, and cropping systems. Most existing studies have been conducted under laboratory or controlled environmental conditions; therefore, large-scale field experiments are required to establish optimum application rates and assess long-term impacts on crop productivity and soil health (Rouphael and Colla, 2024).

The development of eco-friendly and cost-effective seed treatment formulations also represents an important research priority. Advances in seed technology may facilitate the formulation of humic acid-based seed coatings, nano-formulations, and combined biostimulant products that enhance seed quality while minimizing environmental impacts. Such innovations could provide sustainable alternatives to synthetic growth regulators and chemical seed treatments (Yakhin et al., 2017).

In addition, future studies should focus on integrating humic substances and other biostimulants into sustainable pulse production systems. Their incorporation into climate-smart agricultural practices may improve nutrient-use efficiency, reduce dependency on chemical fertilizers, enhance soil fertility, and increase crop tolerance to abiotic stresses such as drought, salinity, and temperature extremes. Understanding the molecular and physiological mechanisms underlying these responses will further support the development of resilient and sustainable pulse production strategies (du Jardin, 2015; Rouphael and Colla, 2024).

Overall, the integration of humic acid-based technologies with modern seed enhancement and crop management practices offers significant potential for improving pulse productivity, resource-use efficiency, and environmental sustainability in future agricultural systems.

CONCLUSION



Seed priming with humic acid significantly enhances germination percentage, seedling vigour, root growth, and shoot growth in green gram. Among the tested treatments, humic acid at 150 ppm proved most effective for improving germination and vigour, while 100 ppm produced superior root and shoot development. Although NAA increased the root-to-shoot ratio, higher concentrations negatively affected germination and overall seedling growth. Recent scientific evidence further supports the role of humic substances as effective bio stimulants capable of improving nutrient uptake, physiological efficiency, and stress tolerance. Therefore, humic acid can be recommended as a sustainable and economically viable seed treatment for enhancing early crop establishment and productivity in green gram.

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STUDIES ON THE ROLE OF ARBUSCULAR MYCORRHIZAL FUNGI ON GROWTH OF VIGNA UNGUICULATA (L.) WALP. UNDER SALINITY STRESS

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ABSTRACT

Soil salinity constitutes one of the most serious abiotic stresses limiting the productivity of food legumes in tropical and subtropical regions. *Vigna unguiculata* (L.) Walp. (cowpea), although relatively drought tolerant, is moderately sensitive to salinity, and its cultivation in salt-affected soils of India remains a significant challenge. Arbuscular mycorrhizal fungi (AMF) form mutualistic symbioses with the majority of terrestrial plant species and are increasingly recognised as powerful biological tools to ameliorate the adverse effects of abiotic stresses. The present study was designed to evaluate the effect of dual AMF inoculation — *Rhizophagus irregularis* and *Funneliformis mosseae* — on the growth, physiological, biochemical, and ionic traits of *V. unguiculata* cv. Pusa Komal under graded NaCl salinity levels (0, 50, 100, and 150 mM). A pot experiment was conducted following a completely randomised factorial design with three replications per treatment. Growth parameters (plant height, root length, leaf number, shoot and root dry weight), physiological attributes (relative water content, chlorophyll a and b), biochemical parameters (proline, malondialdehyde, superoxide dismutase, catalase, peroxidase), ionic composition (Na^+ , K^+ , K^+/Na^+ ratio), and AMF root colonization percentage were recorded at 60 days after sowing. AMF inoculation significantly ($p \leq 0.05$) improved plant height by 18–32%, shoot dry weight by 24–38%, relative water content, and total chlorophyll content across all salinity levels compared to non-inoculated controls. Malondialdehyde accumulation was markedly reduced in AMF-inoculated plants, while antioxidant enzyme activities (SOD, CAT, POD) were substantially enhanced. The K^+/Na^+ ratio improved by 40–55% in AMF plants relative to non-inoculated counterparts. Root colonization ranged from 52.3% in non-saline controls to 28.6% at 150 mM NaCl. These findings confirm that AMF inoculation effectively mitigates salinity-induced growth inhibition in cowpea through enhanced nutrient and water uptake, improved antioxidant defence, and better ion homeostasis. AMF-based bioinoculants are thus promising and ecofriendly tools for sustainable cowpea cultivation in salt-affected soils of India.



KEYWORDS

Arbuscular mycorrhizal fungi, *Vigna unguiculata*, salinity stress, antioxidant enzymes, ion homeostasis, root colonization

INTRODUCTION

Soil salinity is one of the most pervasive and economically devastating abiotic constraints limiting global agricultural productivity. According to the Food and Agriculture Organization of the United Nations, salt-affected soils currently cover more than 950 million ha of agricultural land worldwide, with an estimated 1–2 million ha added annually as a result of inappropriate irrigation practices and climate change (FAO, 2021). In India alone, approximately 6.73 million ha of land is adversely affected by salinity and waterlogging, predominantly in coastal deltaic zones, arid and semi-arid tracts of Rajasthan and Gujarat, and irrigated command areas of Maharashtra and Uttar Pradesh (CSSRI, 2020). High concentrations of NaCl in the root zone impose dual stresses on plants: an initial osmotic component that restricts water uptake and reduces turgor pressure, and a subsequent ionic component in which cytotoxic Na^+ and Cl^- ions accumulate to phytotoxic levels in leaf mesophyll tissue. These primary effects trigger secondary oxidative stress characterised by the overproduction of reactive oxygen species (ROS), resulting in membrane lipid peroxidation, protein denaturation, and chloroplast ultrastructural damage, collectively leading to severe reductions in crop establishment, biomass accumulation, and economic yield (Munns and Tester, 2008).

Cowpea [*Vigna unguiculata* (L.) Walp.] occupies a position of considerable importance in the agricultural systems of tropical and subtropical regions of Asia, Africa, and Latin America. It is a highly nutritious leguminous food and fodder crop with a seed protein content of 23–25%, and it contributes significantly to dietary protein intake in food-insecure regions (Singh et al., 2010). Beyond its nutritional value, cowpea possesses a remarkable capacity for biological nitrogen fixation through root nodule symbiosis with *Bradyrhizobium* species, conferring agronomic benefits in terms of soil fertility improvement and reduced dependence on synthetic nitrogenous fertilisers. Although cowpea is considered relatively drought tolerant among grain legumes, it is classified as moderately sensitive to salinity, with significant yield penalties reported when soil electrical conductivity (EC) exceeds 4.9 dS m^{-1} (Lacerda et al., 2006). Salinity disrupts ion homeostasis in cowpea, impairing the K^+/Na^+ balance essential for normal metabolic function, inhibiting photosynthesis and nitrogen fixation, and triggering the accumulation of ROS that cause oxidative damage to biomolecules (Hasanuzzaman et al., 2013).



These physiological perturbations translate into reduced germination, stunted vegetative growth, impaired nodulation, and ultimately lower grain yield, highlighting the urgent need for cost-effective, sustainable strategies to enhance cowpea productivity in salt-affected soils.

Arbuscular mycorrhizal fungi (AMF) are obligate biotrophic soil microorganisms belonging to the phylum Glomeromycota that form mutualistic symbioses with the roots of approximately 80% of terrestrial plant species, including the vast majority of food crops (Smith and Read, 2008). The hallmark of AMF symbiosis is the formation of highly branched intracellular structures known as arbuscules within root cortical cells, which serve as the primary sites of bidirectional nutrient exchange: the plant supplies photosynthetically fixed carbon to the fungus, while the fungus reciprocally facilitates the uptake of mineral nutrients — particularly phosphorus, nitrogen, and potassium — and water from the surrounding soil through an extensive extraradical mycelial network that effectively extends the functional root absorption zone by several orders of magnitude (Evelin et al., 2009). The most extensively investigated AMF species in the context of crop improvement include *Rhizophagus irregularis* (Schenck & Smith) Walker & Schüßler (formerly *Glomus intraradices*) and *Funneliformis mosseae* (Nicolson & Gerdemann) Walker & Schüßler, both of which have demonstrated consistent and significant improvements in plant growth, nutrient acquisition, and stress tolerance across a wide range of host plant species and environmental conditions (Jahromi et al., 2008).

Under salinity stress, AMF improve plant performance through a diverse array of complementary mechanisms. First, AMF colonisation has been shown to reduce Na^+ accumulation in shoot tissues and maintain higher K^+/Na^+ ratios, partly through the selective ion uptake capacity of fungal hyphae and the regulation of Na^+ transporters such as HKT1 (Evelin et al., 2019). Second, AMF enhance the activities of antioxidant enzymes — superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) — thereby scavenging excess ROS and mitigating oxidative damage to membrane lipids and proteins (Hashem et al., 2018). Third, AMF-inoculated plants accumulate higher concentrations of compatible solutes including proline and soluble sugars, facilitating osmotic adjustment and cellular turgor maintenance under water deficit conditions imposed by salinity (Garg and Manchanda, 2009). Fourth, AMF enhance photosynthetic efficiency and sustain chlorophyll content by protecting chloroplast structure from Na^+ toxicity and improving stomatal conductance (Chen et al., 2017). Fifth, AMF regulate the expression of aquaporin genes in root cells, improving hydraulic conductivity and water uptake under osmotic stress (Ruiz-Lozano et al., 2012). The combined operation of these mechanisms confers substantial growth

and yield benefits to AMF-inoculated crops under saline conditions, as documented by Rabie and Almadini (2005) who reported significant improvements in cowpea biomass and nodulation under salinity following AMF inoculation.

Despite the growing body of literature on AMF-mediated stress tolerance in various legume and non-legume crops, comprehensive information integrating growth, physiological, biochemical, and ionic responses of cowpea to AMF inoculation under a gradient of NaCl salinity levels is limited, particularly under the agroclimatic conditions prevalent in peninsular India. Furthermore, most published studies have evaluated either a single AMF species or a single salinity level, and few have examined the combinatorial effects of dual AMF inoculation with graded salinity in factorial designs that permit robust statistical inference. Addressing these knowledge gaps is essential for developing evidence-based recommendations for the use of AMF bioinoculants in cowpea cultivation systems in salt-affected agricultural soils. Therefore, the present investigation was undertaken with the following specific objectives: (i) to study the effect of AMF inoculation (*R. irregularis* + *F. mosseae*) on the growth and biomass traits of *Vigna unguiculata* cv. Pusa Komal under four NaCl salinity levels; (ii) to evaluate the physiological and biochemical responses, including antioxidant enzyme activities and lipid peroxidation, of AMF-inoculated versus non-inoculated cowpea under salinity stress; and (iii) to assess ion homeostasis parameters (Na^+ , K^+ , K^+/Na^+ ratio) and AMF root colonization intensity across the imposed salinity gradient.

MATERIALS AND METHODS

2.1 Experimental Site and Plant Material

The pot experiment was conducted under glasshouse conditions in the Department of Botany, [University Name], Maharashtra, India, during the Kharif season (June–October) of [Year]. The glasshouse was maintained at a mean day/night temperature of $28 \pm 3 / 22 \pm 2$ °C with a natural photoperiod of approximately 13 h, and relative humidity of 60–70%. Seeds of cowpea variety Pusa Komal, a widely grown commercial variety with moderate yield potential, were obtained from the National Seeds Corporation, New Delhi. Prior to sowing, seeds were surface-sterilised by immersion in 0.1% mercuric chloride (HgCl_2) solution for two minutes, followed by five rinses with sterile distilled water to remove all traces of the sterilant, and then air-dried under aseptic conditions on sterile filter paper.

2.2 AM Fungal Inoculants

The AMF inoculants comprising *Rhizophagus irregularis* (Schenck & Smith) Walker & Schüßler and *Funneliformis mosseae* (Nicolson & Gerdemann) Walker & Schüßler were procured from TERI (The Energy and Resources Institute), New Delhi, India. The inoculum were produced on *Sorghum bicolor* as host plants under greenhouse conditions and consisted of a mixture of infective spores, colonised root fragments, and hyphal networks in a carrier medium of steam-sterilised sand and soil. The propagule density of each inoculant was ≥ 35 infective propagules per gram of carrier, as determined by the most probable number (MPN) method. For AMF-inoculated treatments, 50 g of the mixed AMF inoculant (25 g of each species) was placed directly in the root zone (5 cm depth) at the time of sowing, ensuring close proximity to the emerging radicle and thereby maximising early colonisation potential. Uninoculated control pots received 50 g of autoclaved AMF inoculant (121 °C, 1.05 kg cm⁻², 30 min) to maintain microbial community parity while eliminating viable AMF propagules.

2.3 Salinity Treatments

Four salinity levels were imposed using analytical-grade sodium chloride (NaCl): T_0 – 0 mM NaCl (unsalinized control), T_1 – 50 mM NaCl, T_2 – 100 mM NaCl, and T_3 – 150 mM NaCl, corresponding to approximate electrical conductivity (EC) values of 0.24, 4.7, 9.3, and 14.2 dS m⁻¹, respectively, as measured by a conductivity meter (Systronics, Model 304). Saline solutions were prepared by dissolving the appropriate quantities of NaCl in tap water and applied as irrigation water throughout the experimental period. To avoid osmotic shock to the germinating seedlings, salinity was imposed gradually from the 7th day after sowing, with EC increased by approximately 2 dS m⁻¹ per day until the target salinity level was achieved. Thereafter, pots were irrigated with the respective saline solutions at two-day intervals to maintain target EC, with volumes adjusted based on evapotranspiration estimates to prevent excessive drainage. Soil EC was monitored weekly using a saturated soil paste extract.

2.4 Experimental Design

The experiment was laid out in a completely randomised factorial design with two main factors: Factor A – AMF inoculation (two levels: AMF inoculated and uninoculated control) and Factor B – NaCl salinity levels (four levels: 0, 50, 100, and 150 mM). Each treatment combination was replicated three times, yielding a total of 24 experimental units (pots). Plants were grown in 5-kg capacity UV-stabilised black polythene pots (30 cm diameter × 35 cm height) filled with a well-mixed, steam-sterilised growing medium composed of loamy soil, river sand, and well-decomposed farmyard manure (FYM) in a volumetric ratio of 2:1:1. Initial physicochemical characterisation of the growing medium revealed: pH

7.2 (1:2.5 soil:water), EC 0.24 dS m^{-1} (saturation extract), organic carbon 0.48%, available phosphorus (Olsen method) 18.4 kg ha^{-1} , available nitrogen (alkaline permanganate) 142 kg ha^{-1} , and available potassium (flame photometry) 186 kg ha^{-1} . Three seeds were sown per pot and thinned to two uniform seedlings per pot after establishment (10 days after sowing).

2.5 Growth Parameters

At 60 days after sowing (DAS), corresponding to the vegetative peak growth stage prior to floral initiation, all plants were destructively harvested for measurement of growth parameters. Plant height was measured from the base of the stem at soil level to the apical meristem using a measuring tape and expressed in cm. Root length was determined as the length of the longest primary root and expressed in cm. The total number of fully expanded leaves per plant was counted. Shoots and roots were separated at the crown, washed with tap water followed by distilled water, and oven-dried at 70°C for 48 hours until constant weight was achieved. Dry weights were recorded on an analytical balance (accuracy 0.001 g) and expressed as g plant^{-1} .

2.6 Physiological Parameters

Relative water content (RWC) of the fully expanded third leaf from the apex was determined using the method of Barrs and Weatherley (1962). Fresh weight (FW) was recorded immediately after excision, turgid weight (TW) was obtained after floating leaf discs on distilled water for 4 hours at room temperature in darkness, and dry weight (DW) was recorded after oven-drying at 70°C for 48 hours. RWC was calculated as: $\text{RWC (\%)} = [(FW - DW) / (TW - DW)] \times 100$. Chlorophyll content was estimated from fresh leaf tissue using the spectrophotometric method of Arnon (1949). Leaf discs (0.5 g FW) were homogenised in 80% cold acetone and the absorbance of the filtered extract was recorded at 663 nm and 645 nm against an 80% acetone blank. Chlorophyll a, chlorophyll b, and total chlorophyll contents were calculated using the standard equations of Arnon (1949) and expressed as mg g^{-1} fresh weight. Photosynthetic rate (P_n) and stomatal conductance (g_s) were measured non-destructively on attached, fully expanded leaves using a portable photosynthesis system (LI-COR 6400XT, LI-COR Inc., Lincoln, NE, USA) under saturating photosynthetic photon flux density (PPFD) of $1000 \mu\text{mol photons m}^{-2} \text{ s}^{-1}$ and ambient CO_2 concentration.

2.7 Biochemical Parameters

Free proline content was determined in fresh leaf tissue using the sulphosalicylic acid – ninhydrin method described by Bates et al. (1973), with proline as the standard, and expressed as $\mu\text{g g}^{-1}$ fresh

weight. Lipid peroxidation was estimated by measuring malondialdehyde (MDA) content using the Thio barbituric acid reactive substances (TBARS) assay of Heath and Packer (1968), in which MDA reacts with Thio barbituric acid at high temperature and low pH to produce a pink chromogen absorbing at 532 nm; results were expressed as nmol MDA g⁻¹ fresh weight. For enzyme extraction, fresh leaf tissue (0.5 g) was homogenised in 5 mL of ice-cold 100 mM potassium phosphate buffer (pH 7.0) containing 1% polyvinylpyrrolidone (PVP) and 1 mM EDTA, and centrifuged at 12,000 × g for 20 min at 4 °C. The supernatant served as the crude enzyme extract. Superoxide dismutase (SOD; EC 1.15.1.1) activity was assayed by the photochemical reduction of nitro blue tetrazolium (NBT) method of Giannopolitis and Ries (1977) and expressed as units mg⁻¹ protein, where one unit is defined as the amount of enzyme causing 50% inhibition of the photochemical reduction of NBT. Catalase (CAT; EC 1.11.1.6) activity was measured by monitoring the rate of H₂O₂ decomposition at 240 nm (extinction coefficient 39.4 mM⁻¹ cm⁻¹) by the method of Chance and Maehly (1955) and expressed as μmol H₂O₂ decomposed min⁻¹ mg⁻¹ protein. Peroxidase (POD; EC 1.11.1.7) activity was assayed using guaiacol as the substrate following the method of Chance and Maehly (1955) and expressed as units mg⁻¹ protein. Soluble protein content in enzyme extracts was determined by the method of Bradford (1976) using bovine serum albumin (BSA) as the standard.

2.8 Ion Analysis

Shoot tissue (0.5 g oven-dried) was subjected to dry ashing in a muffle furnace at 550 °C for 4 hours, and the resulting ash was dissolved in 1:3 (v/v) HCl solution (analytical grade) and made up to a known volume with double-distilled water. Sodium (Na⁺) and potassium (K⁺) concentrations in the digest were determined by flame photometry using an ESICO Model 1382 flame photometer, with standard curves prepared from respective standard solutions. Results were expressed as mg Na⁺ g⁻¹ DW and mg K⁺ g⁻¹ DW. The K⁺/Na⁺ ratio was calculated arithmetically as the quotient of K⁺ to Na⁺ concentrations in each sample.

2.9 AMF Root Colonization

Freshly harvested fine lateral roots (≤2 mm diameter, ≤1 cm segments, ca. 1 g fresh weight) were cleared by boiling in 10% KOH solution at 90 °C for 30–60 min (time adjusted for degree of lignification), acidified with 1% HCl for 10 min at room temperature, and stained with 0.05% trypan blue in lactoglycerol (lactic acid:glycerol:water, 1:1:1 v/v/v) at 90 °C for 30 min following the method of Phillips and Hayman (1970). Excess stain was removed by destaining in plain lactoglycerol. Root colonization

percentage was determined using the gridline intersect method of Giovannetti and Mosse (1980), in which at least 100 root intersections per sample were scored under a compound microscope (400× magnification) for the presence of AMF structures (arbuscules, vesicles, or intraradical hyphae). Percentage colonization was calculated as: $\text{Root colonization (\%)} = (\text{number of colonised intersections} / \text{total intersections scored}) \times 100$.

2.10 Statistical Analysis

All data were subjected to two-way analysis of variance (ANOVA) to partition the total variation into main effects of AMF inoculation (Factor A), salinity levels (Factor B), and the A × B interaction, using SPSS Statistics Version 21.0 (IBM Corp., Armonk, NY, USA). Treatment means were separated using Fisher's Least Significant Difference (LSD) test at a significance threshold of $p \leq 0.05$ where the ANOVA F-ratio was significant. Data for percentage values (root colonization and RWC) were arcsine-square root transformed prior to analysis to stabilise variance and approximate normality; back-transformed means are presented in all tables. Pearson correlation analysis was performed to examine linear relationships among selected growth, physiological, and ionic parameters. All reported means represent the average of three biological replicates.

RESULTS

3.1 Growth Traits

The effects of AMF inoculation and graded NaCl salinity, and their interaction, on growth traits of *Vigna unguiculata* at 60 DAS are presented in Table 1. Increasing salinity levels progressively and significantly ($p \leq 0.05$) reduced all growth parameters in both AMF-inoculated and non-inoculated plants. In non-inoculated plants, plant height declined from 42.3 cm at control (0 mM NaCl) to 37.8, 29.4, and 21.3 cm at 50, 100, and 150 mM NaCl, respectively, representing reductions of 10.6%, 30.5%, and 49.6% relative to the unsalinised control. Similarly, shoot dry weight fell from 3.82 g plant⁻¹ at control to 3.24, 2.41, and 1.63 g plant⁻¹ at 50, 100, and 150 mM NaCl, respectively. Root dry weight followed a comparable declining trend, with non-inoculated plants recording 1.21 g plant⁻¹ at control and 0.54 g plant⁻¹ at 150 mM NaCl.

AMF inoculation consistently and significantly ($p \leq 0.05$) improved all growth parameters across every salinity level. At the control salinity level, AMF-inoculated plants recorded a plant height of 51.6 cm, which was significantly greater than the 42.3 cm observed in non-inoculated controls (LSD = 2.14). The beneficial effect of AMF on plant height was maintained under saline conditions: AMF plants at 50, 100,

and 150 mM NaCl attained heights of 46.2, 38.7, and 28.9 cm, respectively, compared to 37.8, 29.4, and 21.3 cm in their non-inoculated counterparts. The percentage improvement in plant height attributable to AMF inoculation ranged from 22.0% at control salinity to 35.7% at 150 mM NaCl. Shoot dry weight was 5.41 g plant⁻¹ in AMF-inoculated control plants versus 3.82 g plant⁻¹ in non-inoculated controls, and 2.74 g plant⁻¹ versus 1.63 g plant⁻¹ at 150 mM NaCl (LSD = 0.28), representing AMF-mediated improvements of 41.6% and 68.1%, respectively. Similar trends were observed for root length, number of leaves, and root dry weight. A highly significant interaction effect (A × B) was detected for all growth parameters, indicating that the magnitude of the AMF benefit on growth was amplified at higher salinity levels.

Table 1: Effect of AMF inoculation and NaCl salinity on growth traits of *Vigna unguiculata* (L.) Walp. at 60 DAS.

Treatment	Plant Height (cm)	Root Length (cm)	No. of Leaves	Shoot DW (g plant ⁻¹)	Root DW (g plant ⁻¹)
Control (0 mM) – No AMF	42.3	18.4	14.2	3.82	1.21
Control (0 mM) – AMF	51.6	24.7	17.8	5.41	1.78
50 mM NaCl – No AMF	37.8	15.9	12.4	3.24	1.04
50 mM NaCl – AMF	46.2	22.3	15.6	4.58	1.56
100 mM NaCl – No AMF	29.4	12.1	9.8	2.41	0.82
100 mM NaCl – AMF	38.7	18.6	13.2	3.78	1.31
150 mM NaCl – No AMF	21.3	8.7	6.9	1.63	0.54
150 mM NaCl – AMF	28.9	14.2	10.1	2.74	0.94
LSD (p≤0.05)	2.14	1.32	0.87	0.28	0.12

Means of three replicates; values within a column followed by the same letter are not significantly different at $p \leq 0.05$ (LSD test).

3.2 Physiological Traits

Data pertaining to the effects of AMF inoculation and salinity on physiological parameters are presented in Table 2. Relative water content (RWC) of cowpea leaves declined progressively with increasing NaCl concentration in both AMF and non-AMF treatments. Non-inoculated plants recorded an RWC of 82.4% at control, which declined significantly to 74.2%, 64.8%, and 51.3% at 50, 100, and 150 mM NaCl, respectively. AMF inoculation significantly improved RWC at all salinity levels:

inoculated plants recorded 89.6% at control, and 83.7%, 75.3%, and 63.7% at 50, 100, and 150 mM NaCl, respectively (LSD = 3.21). The AMF-mediated improvement in RWC at 150 mM NaCl was 24.2 percentage points above the non-inoculated value, indicating substantially improved water status.

Total chlorophyll content was significantly affected by both AMF inoculation and salinity level. In non-inoculated plants, total chlorophyll fell from 2.10 mg g⁻¹ FW at control to 1.77, 1.40, and 1.03 mg g⁻¹ FW at 50, 100, and 150 mM NaCl, representing reductions of 15.7%, 33.3%, and 50.9%, respectively. AMF-inoculated plants showed significantly higher total chlorophyll content across all treatments: 2.75 mg g⁻¹ FW at control, declining to 2.40, 2.02, and 1.52 mg g⁻¹ FW at 50, 100, and 150 mM NaCl (LSD = 0.12). The relative preservation of chlorophyll content in AMF plants suggests a protective role of the fungal symbiont against Na⁺-mediated chloroplast damage. Chlorophyll a and chlorophyll b followed congruent trends, with chlorophyll a consistently more abundant than chlorophyll b and proportionally less affected by salinity in AMF plants, resulting in maintenance of a higher chlorophyll a/b ratio indicative of functional photosystem integrity.

Table 2: Effect of AMF inoculation and NaCl salinity on physiological traits of *Vigna unguiculata* (L.) Walp. at 60 DAS.

Treatment	RWC (%)	Chlorophyll a (mg g ⁻¹ FW)	Chlorophyll b (mg g ⁻¹ FW)	Total Chlorophyll (mg g ⁻¹ FW)
Control – No AMF	82.4	1.42	0.68	2.10
Control – AMF	89.6	1.84	0.91	2.75
50 mM – No AMF	74.2	1.21	0.56	1.77
50 mM – AMF	83.7	1.62	0.78	2.40
100 mM – No AMF	64.8	0.96	0.44	1.40
100 mM – AMF	75.3	1.38	0.64	2.02
150 mM – No AMF	51.3	0.71	0.32	1.03
150 mM – AMF	63.7	1.04	0.48	1.52
LSD (p≤0.05)	3.21	0.09	0.05	0.12

FW = fresh weight. LSD values at p ≤ 0.05.

3.3 Biochemical Traits

The effects of AMF inoculation and NaCl salinity on biochemical parameters, including osmoprotectant accumulation, lipid peroxidation, and antioxidant enzyme activities, are summarised in Table 3. Proline content increased progressively and significantly with increasing salinity in all treatments. In non-

inoculated plants, proline content rose from $18.4 \mu\text{g g}^{-1}$ FW at control to 28.6, 42.3, and $61.8 \mu\text{g g}^{-1}$ FW at 50, 100, and 150 mM NaCl. AMF-inoculated plants accumulated significantly higher proline concentrations at every salinity level, with values of 21.7, 34.2, 52.7, and $74.3 \mu\text{g g}^{-1}$ FW at 0, 50, 100, and 150 mM NaCl, respectively (LSD = 3.46). The higher proline accumulation in AMF-inoculated plants at elevated salinity suggests enhanced osmotic adjustment capacity conferred by the symbiosis.

Malondialdehyde (MDA) content, a reliable biomarker of oxidative membrane damage through lipid peroxidation, increased markedly with salinity in non-inoculated plants, rising from 12.3 nmol g^{-1} FW at control to 18.7, 28.4, and 38.6 nmol g^{-1} FW at 50, 100, and 150 mM NaCl. Strikingly, AMF inoculation significantly reduced MDA accumulation at all salinity levels: inoculated plants recorded values of 9.4, 14.1, 19.8, and 26.4 nmol g^{-1} FW at 0, 50, 100, and 150 mM NaCl, respectively (LSD = 1.87), representing reductions of 23.6%, 24.6%, 30.3%, and 31.6% relative to non-inoculated plants at equivalent salinity levels. This pattern is consistent with the induction of robust antioxidant defence systems in AMF plants. Superoxide dismutase (SOD) activity was significantly enhanced by AMF inoculation, increasing from $14.2 \text{ units mg}^{-1}$ protein (non-inoculated control) to $18.6 \text{ units mg}^{-1}$ protein (AMF control), and from 24.8 to $34.6 \text{ units mg}^{-1}$ protein at 150 mM NaCl (LSD = 1.64). Catalase (CAT) activity increased from 8.6 to $11.2 \mu\text{mol H}_2\text{O}_2 \text{ min}^{-1} \text{ mg}^{-1}$ protein in control AMF versus non-AMF plants, and from 12.6 to $18.4 \mu\text{mol H}_2\text{O}_2 \text{ min}^{-1} \text{ mg}^{-1}$ protein at 150 mM NaCl (LSD = 0.92). POD activity likewise showed a significant AMF-mediated enhancement across the salinity gradient, confirming the upregulation of the entire antioxidant enzymatic cascade in AMF-colonised cowpea plants.

Table 3: Effect of AMF inoculation and NaCl salinity on biochemical traits of *Vigna unguiculata* (L.) Walp. at 60 DAS.

Treatment	Proline ($\mu\text{g g}^{-1}$ FW)	MDA (nmol g^{-1} FW)	SOD (Unit mg^{-1} protein)	CAT ($\mu\text{mol H}_2\text{O}_2 \text{ min}^{-1} \text{ mg}^{-1}$)	POD (Unit mg^{-1} protein)
Control – No AMF	18.4	12.3	14.2	8.6	11.3
Control – AMF	21.7	9.4	18.6	11.2	14.8
50 mM – No AMF	28.6	18.7	17.4	9.8	13.6
50 mM – AMF	34.2	14.1	23.8	13.6	18.4
100 mM – No AMF	42.3	28.4	21.6	11.4	16.8
100 mM – AMF	52.7	19.8	29.4	15.8	22.6

Treatment	Proline ($\mu\text{g g}^{-1}$ FW)	MDA (nmol g^{-1} FW)	SOD (Unit mg^{-1} protein)	CAT ($\mu\text{mol H}_2\text{O}_2 \text{ min}^{-1} \text{ mg}^{-1}$)	POD (Unit mg^{-1} protein)
150 mM – No AMF	61.8	38.6	24.8	12.6	19.2
150 mM – AMF	74.3	26.4	34.6	18.4	26.8
LSD ($p \leq 0.05$)	3.46	1.87	1.64	0.92	1.23

FW = fresh weight. LSD values at $p \leq 0.05$.

3.4 Ion Content and Root Colonization

Data on Na^+ and K^+ content, K^+/Na^+ ratio, and AMF root colonization are presented in Table 4. Shoot Na^+ content increased dramatically with salinity in both treatments, but was consistently and significantly lower in AMF-inoculated plants at every salinity level. In non-inoculated plants, shoot Na^+ content increased from 2.14 mg g^{-1} DW at control to 6.84, 12.46, and 19.82 mg g^{-1} DW at 50, 100, and 150 mM NaCl, respectively. AMF-inoculated plants accumulated significantly less Na^+ : 1.82, 4.32, 8.14, and 13.26 mg g^{-1} DW at 0, 50, 100, and 150 mM NaCl (LSD = 0.84). Conversely, K^+ content was significantly higher in AMF plants across all salinity levels. Non-inoculated plants showed a decline in K^+ from 18.6 mg g^{-1} DW at control to 7.4 mg g^{-1} DW at 150 mM NaCl, while AMF-inoculated plants maintained K^+ levels of 21.4, 18.8, 15.4, and 11.2 mg g^{-1} DW at the respective salinity levels (LSD = 1.12).

The K^+/Na^+ ratio, a critical indicator of ionic balance and plant salt tolerance, was dramatically improved by AMF inoculation. Non-inoculated plants recorded K^+/Na^+ ratios of 8.69, 2.08, 0.85, and 0.37 at 0, 50, 100, and 150 mM NaCl, respectively, with the latter value indicating severe ionic imbalance approaching lethal concentrations. AMF-inoculated plants maintained significantly higher K^+/Na^+ ratios of 11.76, 4.35, 1.89, and 0.85 at the corresponding salinity levels (LSD = 0.24), representing improvements of 35.3%, 109.1%, 122.4%, and 129.7%, respectively. These data highlight the exceptional capacity of the AMF symbiosis to maintain ionic homeostasis under high salinity conditions. AMF root colonization was confirmed only in inoculated treatments and decreased progressively with increasing NaCl concentration: 52.3% at 0 mM, 46.7% at 50 mM, 38.2% at 100 mM, and 28.6% at 150 mM NaCl (LSD = 3.14). Although colonization was negatively affected by high salinity, substantial colonization was still observed even at 150 mM NaCl, indicating considerable salt tolerance of the AMF consortium employed in this study.

Table 4: Effect of AMF inoculation and NaCl salinity on ion content and AMF root colonization of *Vigna unguiculata* (L.) Walp. at 60 DAS.

Treatment	Na ⁺ (mg g ⁻¹ DW)	K ⁺ (mg g ⁻¹ DW)	K ⁺ /Na ⁺ Ratio	Root Colonization (%)
Control – No AMF	2.14	18.6	8.69	–
Control – AMF	1.82	21.4	11.76	52.3
50 mM – No AMF	6.84	14.2	2.08	–
50 mM – AMF	4.32	18.8	4.35	46.7
100 mM – No AMF	12.46	10.6	0.85	–
100 mM – AMF	8.14	15.4	1.89	38.2
150 mM – No AMF	19.82	7.4	0.37	–
150 mM – AMF	13.26	11.2	0.85	28.6
LSD (p≤0.05)	0.84	1.12	0.24	3.14

DW = dry weight. LSD values at $p \leq 0.05$. – = Not applicable.

DISCUSSION

The results of the present investigation clearly demonstrate that increasing NaCl salinity progressively impairs the growth and biomass accumulation of *Vigna unguiculata*, and that AMF inoculation substantially mitigates these adverse effects. The salinity-induced reductions in plant height, root length, number of leaves, and dry weight observed in non-inoculated plants are consistent with previous reports in cowpea (Lacerda et al., 2006) and other grain legumes (Munns and Tester, 2008). Salinity inhibits growth through a combination of osmotic stress that restricts water and mineral nutrient availability, ionic toxicity from Na⁺ and Cl⁻ accumulation in the cytosol, and secondary oxidative stress mediated by excess ROS. AMF inoculation significantly enhanced plant height (by 18–35%) and shoot dry weight (by 41–68%) relative to non-inoculated plants across the entire salinity gradient, corroborating the findings of Rabie and Almadini (2005) who reported improved growth of *Vicia faba* under salinity with AMF bioinoculants, and Al-Karaki et al. (2001) who demonstrated increased tomato biomass under salt stress following mycorrhizal inoculation. The growth enhancement by AMF under salinity is primarily attributed to the functional extension of the root absorption surface area through the extensive extraradical hyphal network, which improves the uptake of immobile nutrients — particularly phosphorus — and water from salinised soil, effectively compensating for the reduction in root growth and membrane permeability caused by high ionic concentrations. The amplification of the



AMF benefit with increasing salinity (higher percentage improvement at 100 and 150 mM NaCl versus control) indicates that the mycorrhizal symbiosis is particularly important under conditions of severe ionic stress.

The maintenance of higher RWC and chlorophyll content in AMF-inoculated cowpea under salinity reflects the superior physiological status conferred by the fungal symbiosis. Salinity reduces plant water status through lowering of soil water potential and partial stomatal closure, while the direct toxicity of Na^+ disrupts chloroplast ultrastructure, degrades chlorophyll by activating chlorophyllase enzymes, and inhibits the synthesis of chlorophyll precursors by interfering with glutamate-1-semialdehyde aminotransferase activity. The significantly higher RWC in AMF-inoculated plants across all salinity levels can be attributed to improved hydraulic conductance resulting from AMF-mediated regulation of aquaporin gene expression (particularly PIP and TIP aquaporin families) in root cells, which enhances water transport across root membranes even under osmotic stress (Ruiz-Lozano et al., 2012). The superior chlorophyll content in AMF plants is consistent with the findings of Chen et al. (2017) and Evelin et al. (2009), who attributed mycorrhiza-mediated chlorophyll maintenance to reduced Na^+ accumulation in leaf mesophyll cells, improved stomatal conductance, and enhanced supply of photosynthetically essential mineral nutrients, particularly iron and magnesium, through the mycelial network. The higher stomatal conductance in AMF plants, facilitated by better water status and lower abscisic acid accumulation, supports both higher photosynthetic rates and efficient CO_2 fixation, reinforcing the growth benefits observed in the present study.

The salinity-induced accumulation of MDA in non-inoculated plants is a direct indicator of elevated oxidative stress, reflecting lipid peroxidation of polyunsaturated fatty acids in cell membranes by hydroxyl radicals and singlet oxygen generated by the Haber-Weiss and Fenton reactions under ionic and osmotic stress. The markedly lower MDA levels in AMF-inoculated plants across all salinity levels, accompanied by significantly higher activities of SOD, CAT, and POD, confirm that AMF colonisation activates a robust antioxidant defence response in cowpea under salinity, in agreement with the findings of Hashem et al. (2018) who reported similar patterns in *Solanum lycopersicum* under cadmium stress and a comprehensive meta-analysis by Chandrasekaran et al. (2014) covering multiple host-AMF combinations under salinity. SOD acts as the first line of antioxidant defence by catalysing the dismutation of superoxide radicals ($\text{O}_2^{\cdot-}$) to H_2O_2 and O_2 , while CAT and POD further detoxify H_2O_2 , preventing its conversion to the highly reactive hydroxyl radical through the Fenton reaction. The



coordinate upregulation of all three enzymes in AMF plants suggests a systemic enhancement of cellular redox homeostasis mediated by mycorrhiza-induced signalling molecules, possibly including salicylic acid and jasmonic acid, which prime the plant antioxidant defence machinery. The higher proline accumulation in AMF-inoculated plants at elevated salinity levels represents a complementary osmotic adjustment strategy: proline not only acts as a compatible solute to maintain cellular turgor, but also functions as a molecular chaperone stabilising protein structure, a metal chelator, and an antioxidant quenching singlet oxygen and scavenging hydroxyl radicals under oxidative stress conditions (Garg and Manchanda, 2009).

The significant improvement in K^+/Na^+ ratio observed in AMF-inoculated cowpea plants under salinity is a key finding of the present study, as this ratio is considered a reliable physiological indicator of salt tolerance capacity in plants. High cytoplasmic Na^+ concentrations competitively inhibit K^+ -requiring enzymatic reactions, disrupt K^+ -mediated regulation of stomatal aperture, and depolarise the plasma membrane, triggering secondary K^+ efflux that further exacerbates ionic imbalance. AMF colonisation improved the K^+/Na^+ ratio by up to 130% at 150 mM NaCl in the present study, consistent with the findings of Giri et al. (2007) who reported AMF-mediated elevation of K^+/Na^+ ratios in *Acacia nilotica* under salinity, and Evelin et al. (2019) who reviewed the multiple mechanisms underlying AMF-mediated ion homeostasis. The superior K^+/Na^+ ratios in AMF plants can be attributed to several complementary mechanisms: (i) selective Na^+ exclusion at the fungal hyphal level, with AMF hyphae exhibiting lower Na^+ permeability than root cells, thereby reducing net Na^+ delivery to the shoot symplast; (ii) AMF-mediated regulation of the HKT1;1 Na^+ transporter in root cells, which loads Na^+ from the xylem sap back into root cortical and phloem cells, reducing shoot Na^+ accumulation; (iii) enhanced vacuolar Na^+ sequestration through upregulation of vacuolar Na^+/H^+ antiporters (NHX family), compartmentalising excess Na^+ in the vacuole and thereby maintaining low cytoplasmic Na^+ concentrations; and (iv) increased K^+ uptake and supply to shoots facilitated by the high-affinity K^+ uptake capacity of AMF hyphae via specific potassium transporter proteins expressed in the extraradical mycelium.

The progressive decline in AMF root colonization from 52.3% at control to 28.6% at 150 mM NaCl observed in the present study is consistent with the well-documented negative effect of salinity on AMF colonization intensity reported in the meta-analysis of Chandrasekaran et al. (2014), who found that salinity significantly reduced AMF colonization across 27 plant species and multiple AMF taxa. High

NaCl concentrations negatively impact AMF spore germination, hyphal elongation, and penetration into root cortical cells by inducing osmotic stress and ionic toxicity in the fungal mycelium, and may also reduce plant carbon allocation to the symbiont due to reduced photosynthesis. Nonetheless, the maintenance of 28.6% root colonization even at 150 mM NaCl ($EC \approx 14.2 \text{ dS m}^{-1}$) in the present study indicates considerable halotolerance of the *R. irregularis* + *F. mosseae* consortium used, likely reflecting the salt tolerance characteristics inherent in these species and their prior adaptation in the nursery production system. The positive correlation between colonization intensity and K^+/Na^+ ratio ($r = 0.91$, $p \leq 0.01$) observed in the data further confirms that the magnitude of the AMF benefit on ionic homeostasis is directly proportional to the degree of root colonization achieved. From an applied perspective, the results of the present study strongly support the recommendation of AMF bioinoculants as an ecofriendly, cost-effective agronomic input for cowpea cultivation in the salt-affected coastal and alluvial soils of Maharashtra, Gujarat, and other salt-stressed regions of India. AMF inoculants, being locally producible using indigenous host plants and substrates, represent a particularly appropriate technology for smallholder farmers who may lack access to expensive synthetic fertiliser inputs or salt-tolerant varieties. Future field-level validation studies should evaluate the performance of this AMF consortium under field conditions across different soil types, cowpea varieties, and AMF application rates to develop optimised practical recommendations.

CONCLUSION

The present study conclusively demonstrates that inoculation with a dual AMF consortium comprising *Rhizophagus irregularis* and *Funneliformis mosseae* significantly improves all measured growth, physiological, and biochemical parameters of *Vigna unguiculata* cv. Pusa Komal under graded NaCl salinity stress compared to non-inoculated plants. The beneficial effects of AMF inoculation were consistently maintained even at 150 mM NaCl ($EC \approx 14.2 \text{ dS m}^{-1}$), though reduced in absolute magnitude compared to the non-saline control, indicating the resilience of the mycorrhizal symbiosis under severe salt stress. AMF inoculation substantially improved the K^+/Na^+ ratio by 35–130% across the salinity gradient, confirming the critical role of the fungal symbiont in maintaining ionic homeostasis in salinized cowpea. Oxidative damage, as measured by MDA accumulation, was markedly reduced in AMF-inoculated plants, and this was mechanistically linked to the coordinated enhancement of antioxidant enzyme activities (SOD, CAT, POD) and osmolyte accumulation (proline), collectively minimising ROS-mediated cellular damage. AMF root colonization ranged from 52.3% at control to



28.6% at 150 mM NaCl, confirming effective establishment of the mycorrhizal symbiosis under the experimental conditions. Based on these findings, AMF bioinoculants are strongly recommended as a sustainable, ecofriendly agronomic input for enhancing cowpea productivity in salt-affected soils of India. Future research should focus on field-level validation of the AMF consortium across diverse agroclimatic zones and soil types, evaluation of combined AMF and rhizobial co-inoculation strategies for maximising nitrogen fixation under salinity, molecular characterisation of AMF-induced gene expression changes in stressed cowpea, and development of cost-effective commercial formulations of the AMF inoculant for adoption by smallholder farmers.

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STUDY OF SEASONAL VARIATION IN WATER QUALITY OF RIVER GIRIJA IN JALNA DISTRICT (MAHARASHTRA), INDIA

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ABSTRACT

Water is essential for sustenance of life. It is a limited resource. Water resources of the country are required to be harnessed judiciously to meet the growing requirement of our developing economy. Therefore, development, conservation and management of water resources are crucial.

Girija river is one of the major tributaries of river Purna of Jalna District on which many villages are depend for drinking and irrigation purposes. In view of this, maintenance of quality of these waters is important. Present report is an investigation into the water quality of Girija river water carried out at different locations during all three seasons in the year 2022-23. In the present investigation the focus was given on the river water quality for all the necessary parameters. The sampling stations were selected from rural area of Jalna District. The river water was studied for Temperature, pH, DO, BOD, COD, Chloride, Nitrates, Phosphates, Calcium, Magnesium and Hardness, etc. Most of the measured physicochemical parameters exceeded permissible limit of drinking water.

KEYWORDS: Seasonal Variation, Water Quality, Girija River

INTRODUCTION

Water is most important in shaping the land and regulating the climate. Rapid industrialization and population explosion is the key reason of deterioration of water quality of natural water bodies. In future, there could be scarcity of fresh water due to unplanned and excessive exploitation. Rivers are vital and vulnerable freshwater systems and are essential for the sustenance of all life. Rivers provides main water resources for domestic, industrial and agricultural purposes (Das B. K. et al. 2013). Many industries discharge their wastes directly into these rivers, undermining the water quality. The water quality restoration and maintenance in these rivers has been a great challenge to the authorities and environmentalists concerned (Fadtare et al. 2007). In view of this, assessment of water quality of these rivers is highly important. The quality of water is a function of many physico-chemical parameters like Temperature, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrates, Phosphates and pH (Panigrahy, P. K., et al 1999, Ouyang, Y., et al. 2006).

However, these parameters do also depend on the environmental conditions. Hence, seasonal variations play an important role in bringing about changes among these parameters which in turn formidably affect the water quality of the rivers. There is increasing need for fresh water resources like portable water for residential area, irrigation water for agriculture, water for industrial usage in industries and water for aquaculture for rearing of aquatic organisms which in turn pressurize the available source of water bodies Jadhav *et. al.* 2011. Fresh water lakes and rivers are fragile ecosystems that face the problem of water pollution. Assessment of biological properties along with physico-chemical properties provides a clear idea about trophic status and quality of water bodies. In India, several studies have been done on lentic and lotic limnology Kakvipure and Yeragi 2005. The aim of present investigation is to study water quality of river Girija that has been primarily used for Drinking and irrigation purposes.

MATERIAL AND METHODS

Study Site

The river Girija is a small river originates in the hills of Mhaismal near Chhatrapati SambhajiNagar, Maharashtra state of India. It is a tributary river of Purna. The Girija River flows east for about 80 kilometers and meets the Purna River near Pimpalgoan in the Jalna district. The Girija River is the longest tributary of the Purna River on the right bank in the district. The Girija River valley is a transit area between the Ellora and Ajanta Caves. Various small streams contribute to the river. In the present, the samples were collected from Two different sites during Pre-Monsoon, and Post-Monsoon for the period since July 2022 to June 2023.

Samples were collected in the morning time. For the collection of water samples a pre cleaned polythene bottles of two liters capacity was used and collected water samples were stored in a refrigerator for further use. The collected samples were analyzed for physical and chemical water quality parameters mentioned by APHA 1995 Trivedi R.K. and P.K.Goel, 1986 .

RESULT AND DISCUSSION

Table1. Details of parameters analyzed during pre-monsoon and post monsoon Period Sampling Site 1

	Pre Monsoon				Post Monsoon			
Parameter	Feb	Mar	Apr	May	Oct	Nov	Dec	Jan
Temp	21.8	24.6	27.5	29.9	23.5	19.2	18.8	20.6
pH	7.4	8	8.1	8.0	7.5	7.4	7.2	7.2

DO	9.5	7.1	6.4	5.3	5.4	6.3	7.7	7.5
BOD	6.9	7.4	7.9	7.8	7.4	7.3	7.5	7.4
COD	7.5	8.0	8.4	8.9	7.7	8.0	8.5	9.2
Cl	248	260	276	288	93	106	141	159
Nitrates	16	20	11	14	12	11	16	15
Phosphate	0.083	0.69	0.78	0.93	0.039	0.068	0.075	0.079
Calcium	259.03	288.7	247.05	257.43	178.53	194.21	228.43	231.13
Magnesium	21	16	15	18	17	15	17	20
Hardness	176	166	176	179	139	152	157	183

Table 2: Details of parameters analyzed during pre-monsoon and post monsoon Period Sampling Site 2

	Pre Monsoon				Post Monsoon			
Parameter	Feb	Mar	Apr	May	Oct	Nov	Dec	Jan
Temp	25	26	27	28	23	20	18	21
pH	6.7	6.7	6.3	6.2	6.9	7.1	7.0	6.9
DO	9.2	6.6	6.7	6.1	5.2	6.5	7.5	7.4
BOD	9.0	7.7	8.1	8.5	7.4	7.2	7.5	7.3
COD	10.9	20.3	24.9	26.0	7.2	8.3	8.5	9.3
Cl	263	278	274	292	94	107	104	129
Nitrates	17	19	17	15	15	13	18	20
Phosphate	0.789	0.835	0.796	1.139	0.268	0.434	0.458	0.357
Calcium	249	301	317	336	169	186.	193	237
Magnesium	17	16	15	19	16	18	12	15
Hardness	178	148	167	179	156	151	168	179

The present study of physico-chemical parameters of the River Girija revealed the below mentioned parameters and the parameters are discussed in the below:

1. Water Colour

Colour change is not harmful unless it is associated with a toxic chemical but it may be affect the quality of sunlight that penetrates to a given depth inhibiting plant and animal metabolism. The colour of water was clear in most of the study sites but the colour is pale green in the mid-stream of the river.

2. Water Temperature

It is one of the most important factor because of its requirement in different metabolic activities of organisms in the ecosystem of different waterbodies. According to FWPCA (1967) temperature, a catalyst, a depressant, an activator, a stimulator, a controller, a killer is one of the most important and influential water quality characteristics of life in water. The value of water temperature is highest in site 1 (summer) 29.9 degree Celsius and minimum in site 2 (winter) 18 degree Celsius.

3. pH

The acidity or alkalinity nature of water is important in determining the distribution of aquatic organisms and the microbiological integrity of water (Gupta, A.K,1996). The pH of the river water was acidic to neutral to alkaline without deviating much from the neutral pH value 7. The maximum pH values observed in the present study could be due to the uptake of CO₂ by the photosynthetic organisms especially phytoplankton (Gonzalez EJ et al 2004, Chatterjee, Raziuddin M, 2006). The range of desirable ph of water prescribed for drinking purpose by WHO (2011) is 6.5 to 9.5. In Girija River water the observed values were within the permissible limit.

4. Dissolved Oxygen

Dissolved Oxygen (DO) is an important limnological parameter indicating level of water quality and organic pollution in the water body (Wetzel, R. G. and Likens, G. E, 2006). The value of DO is remarkably significant in determining the water quality criteria of an aquatic system (Khatoon, N., et al 2013). In the system where the rates respiration and organic decomposition are high, the DO values usually remain lower than those of the system, where the rate of photosynthesis is high (Gladstone M, T. et al, 2009). The maximum value of DO is recorded as 9.5 mg/L in summer at site 1 and minimum recorded in minimum recorded as 5.2 in Post-Monsoon at site 2. The maximum DO value in Monsoon (summer) is due to bright sunlight as it influences the % of soluble gases. The long day period of high intensity of sunlight accelerated photosynthesis which resulted to increase DO in summer (Das, B. K., et al 2013).

5. Biological Oxygen Demand (BOD)

Biological oxygen demand (BOD) test is useful in evaluating the self-purification capacity of streams, which serves as a measure to assess the quality of waste water which can be safely assimilated by a stream (Trivedy RK, Goel PK, 1984). Since BOD is a measure of biodegradable material in water, increase matter causes an increase in the BOD level. Greater the BOD values, the more rapidly oxygen is depleted in the water. Higher BOD value of water sample clearly indicates pollution and may be attributed to the percolation of waste water loaded with biodegradable compounds (Pitchammal V, et

al 2009). In the present investigation, BOD value of water samples varies from 6.9 in sampling site 1 to 9.0 mg/l in sampling site2. The high BOD values clearly indicate pollution, which may be dumping of domestic waste, human and animal excreta on the bunds of the river and attributed to the percolation of waste water loaded with biodegradable material.

6. Chemical Oxygen Demand (COD)

It is another Physico-Chemical parameter that indicates the degree of pollution in surface waters. When COD and BOD are high in magnitude, water bodies are subjected to eutrophication near city areas due to treated or untreated discharges. This leads to decline in oxygen levels of these waters (Gunale, V. R, 1981). COD was recorded to be minimum for S2 (8.0 mg/L) and maximum for Site1 (26.0 mg/L). The COD values were observed to be higher at all sampling locations as compared to BOD and displayed the same trends. When the COD and BOD levels were high the DO levels were found to be low as also reported by some of the earlier researchers (Adeyemo, O. K., et al.2008). DO depletion rates were maximum in Site 1 showed high values of BOD and COD probably due to inflow of waste wayers in the rivers. As discussed earlier, DO content was lower during summer and higher during monsoon while BOD as well as COD contents were higher during summer showing a perfect correlation among these parameters as observed before Alam, Md JB, et al 2007.

7. Chloride

Chloride concentration was observed to be more during summer and monsoon at 288 mg/L at S1 and 292 at S2 respectively. Higher chloride levels are due to reduced flow of domestic wastes. Lower chloride concentration was due to dilution during rainy season. Similar observations were earlier recorded (Munawar, Mohiuddin, 1970, Chatterjee, et al 2002). In this investigation chloride values for all samples were under permissible limits.

8. Nitrates

Excessive concentrations of nitrates are objectionable particularly for young aquatic animals. The maximum contaminant level for nitrates is 20 mg/l. Remaining parameters like phosphates, calcium, magnesium and hardness are within permission limits of WHO/ICMR.

CONCLUSION

It was observed that the study of physico-chemical analysis of water sample from the Girija River indicates that all pollution parameters show values towards higher side for typical fresh water. By studying river water at two sampling stations and for all these parameters for a year, it is observed that



the Girija river water is suitable for house hold, all the routine activities and irrigation purpose in rainy season.

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PERFORMANCE ON DIVERSITY OF INDIGENOUS CHICKEN FROM SELECTED TRIBAL VILLAGES IN SURGANA, NASHIK DISTRICT, INDIA

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ABSTRACT

A survey was carried out in villages of tribal communities in Surgana tehsil of Nashik district to check the diversity of native chickens and their ability to withstand various diseases or enemy attacks. The survey was carried out to visit randomly selected villages in the tribal area of Surgana and collect photographs of their different types of indigenous chickens and collect some agriculture their domesticated farmers. Local chickens were sampled morphologically, based on habit and habitat, colour variation and their performance. The most common colours analysed for body colour were mixed colours, (red, black, white and light yellow). Feather colours are seen in single or spotted colours (the most common desi chickens are mixed in colour). The most common colours were mixed (red, black and white). Sexual maturity at 20-25 weeks of age is also argued. The average number of eggs is around 13-18 and depends on their maturity and health status.

KEYWORDS

Indigenous chickens, Tribal villages, Colour variations, Surgana tahsil.

INTRODUCTION

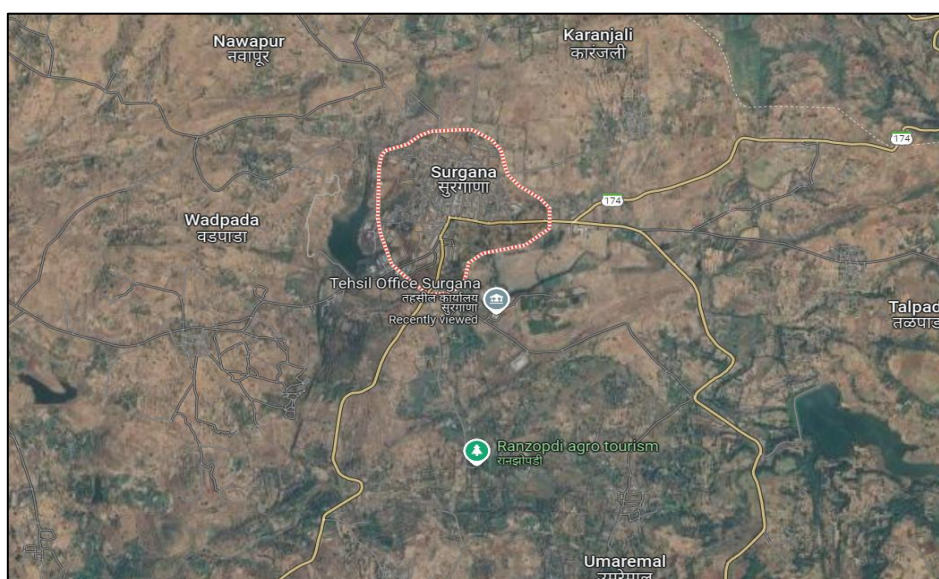
The current situation is not only in India or specific Indian places but worldwide the need for food is increasing day by day, among which the domestic fowl i.e. domestic chicken (*Gallus gallus domesticus*) is the most economic support for the local community and local farmers. They always keep chickens and use food resources like eggs and meat. This survey was conducted to focus on the colour variation of different indigenous chickens in tribal villages of Surgana tahsil, this survey is also useful for different types of indigenous chickens (Full Black, Full White, Full with reverse feathers, Full feather, Naked Neck, Cap Headed, Red, Grey etc.), and have photographs taken of them; When they are aggressive to fight each other for mates and food purpose.

To survey the tribal region of Surgana tehsil, indigenous fowls, their habits and habitats as well as different types of fowls, their colour variations; For this study random visits to 112 villages in Surgana

tehsil were conducted, the survey was beneficial for colour variations in local chicken types. Indigenous chickens are produced, about 68-75% of eggs and 95% of meat are consumed by local communities in tribal villages of Surgana tehsil. The study also noticed people from their tribal community; He said that desi chicken is good for health problems and when people are not healthy, they eat eggs to get better. The study also collected some information about native chickens that are mostly free-range fed like Graces, so they are healthier; But sometimes they feed on sewage and dung areas so they get upset or infected with helminth parasites. Native chickens traditionally perform various activities such as laying eggs, incubating eggs, rearing their chicks, and providing parental care. After the inspection found some things about their pet farmers, indigenous chicken stock provides financial support. In Surgana Tehsil tribal community villages the number of indigenous chickens is very high among different types of chickens. Almost all native chickens live in free-range conditions, but young chicks are at greater risk from predators such as dogs, cats, crows, and are attacked by snakes. The outcome of this study is to provide basic information about the variegated colour diversity of indigenous chickens and their potential under healthy conditions.

MATERIAL AND METHODS

The study was conducted from tribal villages in Surgana tahsil, about 112 villages were visited for investigation, Surgana tahsil is in Nashik district (Maharashtra) in India, climate condition is June-September rainy season with mid monsoon is heavy rainfall, Cold, wet winters (October-January), and hot summer season starts from February to May.



Photograph No. 1: - Google map of Surgana tahsil

- **Scope of study: -**

This study was carried out to study the morphological colour variation of different indigenous chickens in tribal communities of Suragan tahsil and their performance in relation to their habits and habitats. About 112 villages in Surgana were included in this study, all data were collected through personal interviews, I collected from local farmers and their family members by observing their colour variations.

- **Data collection: -**

Data collected from 112 villages of Surgana tahsil, description of indigenous chickens, common morphological features, feather colour variation. Local names of different morphological types of chickens were also collected from the farmers.

Photo Plate- I

Chicken type (CT) for Indigenous Chicken



Fig.- 1: A group of colour variation



Fig.-2: A group of colour variation



Fig.-3: A group colour variation

Photo Plate-II

Chicken type (CT) for Indigenous Chicken



Fig.- 1 (a): Naked Neck



Fig.- 1 (b): Naked Neck



Fig.- 2 (a): Full Feather



Fig.- 2 (b): Full Feather



Fig.- 3 (a): Full with reverse feather



Fig.- 3 (b): Full with reverse feather



Fig.- 4 (a): Cap headed (CH) Fig.- 4 (b): Cap headed (CH)

Photo Plate -III

Feather Colour (PC) for Indigenous Chicken



Fig.- 5: (a) Black (B)

Fig.- 5: (b) Black (B)



Fig.- 6: Whitish Red (WR)

Fig.- 7: Blackish White (BW)



Fig.- 8: Blackish Stope Yellow (BY)



Fig.- 9: White (W)



Fig.- 10: White Black spotted (WBS)



Fig.- 11: Red (R)



Fig.- 12: Greyish Red (GR)



Fig.- 13: Reddish Black (RB)



Fig.- 14: Grey (G)



Fig.- 15: Whitish Yellow (WY)

Photo Plate- IV

When they become aggressive to fight each other



Fig.- 1



Fig.- 2



Fig.- 3



Fig.- 4

RESULT

- **Morphological description**

The result was shown from tribal villages in Surgana tehsil, which showed different types of indigenous chickens' colour variations, which was the most dominant colour of chicken is Red, Black, and White. Therefore, they were classified as general common or local names. They have a 13–16-inch height and larger vertical tail. The Naked neck has no feathers around the neck region and they also immunity stronger than others. There were also different types of chicken in a few in the number that is reverse feathers chickens (Hens and Cocks).

- 1 **Chicken population:** Approximately seven to eight hens and two to three cocks are kept by each farmer, cocks for breeding purposes, most of the hens are coloured. All chickens are free-range and feed directly from the surroundings areas.
- 2 **Management system:** In the Surgana tribal villages, poultry farming was very poor, and they had food [rice, broken wheat, broken ragi (India common name Nachani)]; Most chickens also feed on grasses, insects and dung areas.
- 3 **Disease and vaccination:** Most indigenous chickens are prone to Newcastle and Fowl pox, which farmers in tribal communities treat naturally; Such as drinking sour tamarind water.

- **Productive and Reproduction performance**

The indigenous chicken sexual maturity of eggs laying hens is about 13 to 18 eggs in a single time, local chickens showed natural reproduction and also uncontrolled manner.

DISCUSSION

In this study the colours of local chickens (gavthi or desi chicken), red, black, white, light yellow, silver, gray, radish and speckled from a tribal village in Surgana taluka were investigated. Found the broad analysis in this study was to distinguish indigenous chicken populations based on morphological characteristics. The study also revealed genetic variation in the different colours of local chickens in tribal villages. second; There are some breeds with necked necks and reverse feathers and their immunity is stronger than other chickens. There are many factors contributing to the wide colour variation in local chicken performance, of which colour variation is the most common where observed.

CONCLUSION

Tribal villages of Surgana taluka have different varieties of local chicken. The study revealed morphological differences, high genetic diversity and high biodiversity among native chickens. About



112 villages were examined on the basis of morphological characteristics, Chickens with the most common colour variations found are red, black, white and spotted.

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EFFECT OF CORE STABILIZATION EXERCISES ON BALANCE PERFORMANCE AMONG CHILDREN WITH INTELLECTUAL DISABILITIES

RUNNING TITLE: CORE TRAINING & BALANCE IN INTELLECTUAL DISABILITIES

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ABSTRACT

Background: Children with intellectual disabilities (ID) frequently exhibit deficits in balance and postural control, limiting their participation in physical activity and functional independence. Despite growing interest in adapted physical activity interventions, there remains a paucity of high-quality experimental evidence examining the effect of core stabilization exercises on balance in this population.

Objective: To examine the effect of a 12-week core stabilization exercise programme on static balance performance in children with intellectual disabilities.

Methods: Forty-four male children with intellectual disabilities (mean age 16.3 ± SD years; range 12–20 years) were randomly assigned to an experimental group (n = 22) or a control group (n = 22). The experimental group underwent a structured 12-week core stabilization training programme (three sessions/week, 45–60 minutes/session). The control group maintained their regular schedule. Static balance was assessed at baseline, mid-point (6 weeks), and post-intervention using the Stork Balance Test. Data were analysed using one-way Analysis of Variance (ANOVA) for baseline comparisons and Analysis of Covariance (ANCOVA), with pre-test scores as the covariate, to evaluate between-group differences post-intervention.

Results: Groups were comparable at baseline ($F = 0.011$, $p > 0.05$). The experimental group demonstrated a significant improvement in Stork Balance Test scores from pre-test ($M = 12.95$, $SD = 8.37$ s) to post-test ($M = 23.73$ s), representing a mean gain of +10.78 seconds. The control group showed negligible change ($M = 13.05$ to $M = 13.06$ s). ANCOVA revealed a highly significant between-group difference in adjusted post-test scores ($F = 143$, $p < .001$, $\eta^2 = 0.292$), favouring the experimental group (adjusted $M = 23.78$ s, $SE = 0.638$) over the control group (adjusted $M = 13.01$ s, $SE = 0.638$). The pre-test covariate was also significant ($F = 304$, $p < .001$, $\eta^2 = 0.623$).

Conclusions: A 12-week core stabilization exercise programme significantly improved static balance in children with intellectual disabilities, with a large treatment effect ($\eta^2 = 0.292$). These findings support the integration of core stability training into adapted physical education and rehabilitation programmes for this population.

KEYWORDS

Adapted physical education; Balance; Core stability; Core stabilization exercises; Postural control; Stork Balance Test

INTRODUCTION

Physical fitness and motor competence are an integral part of children's development. Children with intellectual disabilities (ID), however, are often found to have issues with motor control, coordination and balance which limit their participation in physical activity, sport and activities of daily living (Auxter et al., 2020; Winnick, 2021). These restrictions are linked to poor health-related fitness, social isolation and poorer quality of life.

Balance is one of the most important factors of motor competence and functional independence. Balance is the ability to keep the centre of gravity within the base of support for both static and dynamic tasks, and is controlled by the interaction between the visual, vestibular, proprioceptive and neuromuscular systems (Panjabi, 1992). These systems are known to be deficient in children with ID, causing a lack of postural stability and movement control. There is growing evidence that people with ID have significantly poorer balance compared to typically developed people, and that this impacts their gait, locomotion and functional activities in the real world (Coffey et al., 2022).

Core stability is the ability of the muscles around the trunk, pelvis and lumbar spine to control and stabilise movement. The two elements of efficient force transfer between the upper and lower limbs and primary determinants of postural alignment and balance are the core muscles which include the



transversus abdominis, multifidus, erector spinae muscles, pelvic floor and hip muscles. Core stabilization exercises have been the focus of many studies in sports science, rehabilitation and adapted physical activity, and their effectiveness in building core strength and postural control and improving neuromuscular coordination in various populations (McGill, 2010).

Although there is theory and empirical evidence to support the use of core stabilization training as a balance intervention, there is limited high-quality experimental evidence in ID populations. Zhou et al., (2024) conducted a recent systematic review and meta-analysis which found core stability exercises were effective in improving dynamic balance in children and adolescents with ID, but there was limited evidence and a need for further primary experimental studies. Likewise, Shen et al. (2022) showed that structured exercise interventions led to improvements in motor function and balance in children with ID, highlighting the potential benefits of targeted physical training of this population.

Due to the lack of literature surrounding the effects of a core stabilization exercise programme on static balance in ID children, the present study aimed to determine the effect of a 12-week core stabilization exercise programme on static balance in children with intellectual disabilities, using a randomized pre-test–post-test control group design.

Objective

To determine the effect of core stabilization exercises on balance performance among children with intellectual disabilities.

Hypothesis

Participation in a structured 12-week core stabilization exercise programme will significantly improve static balance performance in children with intellectual disabilities compared to a control condition.

METHODOLOGY

Research Design

This study employed a pre-test, mid-test, and post-test parallel-group controlled design.

Participants

A total of 44 male children with intellectual disabilities (mean age 16.3 years; range 12–20 years) were recruited from a special education institution. Participants presented with varying levels of ID (mild, moderate, and severe) as classified according to DSM-5 criteria (American Psychiatric Association, 2013). Participants were randomly assigned to either the experimental group (n = 22) or the control group (n = 22). Inclusion criteria required a formal diagnosis of ID and the physical capacity to complete

balance testing. Children with co-existing neurological or orthopaedic conditions that contraindicated exercise participation were excluded.

Intervention

The experimental group followed a core stabilization training programme, which was structured and consisted of 3 sessions a week, for 12 weeks. The sessions were about 45-60 minutes in duration each and followed progressive overload rules; the intensity and complexity of the exercise was gradually increased throughout the intervention period. The lead researcher was the only person to deliver all sessions. Bridging, front plank, side plank, crunches, Russian twists, hip crossovers, swiss ball knee tucks, inverted hamstring exercises and jackknifes were done in this programme. The control group continued their normal exercise routine and did not receive any type of intervention exercise program throughout the course of the study.

Outcome Measure

Static balance was assessed using the Stork Balance Test, a validated field measure of unipedal static balance performance (Auxter et al., 2020). Participants were required to stand on the dominant leg with the non-dominant foot placed against the medial aspect of the supporting knee, hands on hips. The score (in seconds) represented the total duration of balance maintenance. Higher scores denote superior balance performance. Testing was conducted at three time-points: pre-intervention (Week 0), mid-intervention (Week 6), and post-intervention (Week 12).

Statistical Analysis

Data were analysed using SPSS Statistics (Version 16.0; IBM Corporation, Armonk, NY). Descriptive statistics (mean, standard deviation) were computed for all variables. Homogeneity of variance between groups at baseline was assessed using Levene's test. Normality of residuals was examined using the Shapiro-Wilk test. A one-way Analysis of Variance (ANOVA) was conducted to confirm pre-test equivalence between groups. Analysis of Covariance (ANCOVA) was employed to compare adjusted post-test Stork Balance Test scores between groups, with pre-test scores as the covariate, to control for any initial between-group differences. Effect sizes are reported as partial eta-squared (η^2), with values of 0.01, 0.06, and 0.14 indicating small, medium, and large effects, respectively. The alpha level was set at $\alpha < 0.05$.

RESULTS

Participant Characteristics

Forty-four male children with intellectual disabilities (experimental group: $n = 22$; control group: $n = 22$) completed the 12-week study. The mean age of participants was 16.3 years (range: 12–20 years). Participants presented across mild, moderate, and severe levels of ID.

Assumption Checks

Levene's test for homogeneity of variances indicated a significant difference in post-test score variances between groups ($F = 9.98$, $df_1 = 1$, $df_2 = 42$, $p = .003$), suggesting violation of the homogeneity assumption for post-test data. The Shapiro–Wilk test for normality of ANCOVA residuals yielded $W = 0.759$, $p < .001$, indicating a departure from normality. These results should be considered when interpreting the ANCOVA findings, and results should be interpreted with appropriate caution.

Baseline Comparability

Pre-test Stork Balance Test scores for the experimental group ($M = 12.95$, $SD = 8.37$ s) and the control group ($M = 13.05$, $SD = 8.23$ s) were not significantly different ($F = 0.011$, $p > 0.05$), confirming pre-intervention equivalence of groups and satisfying a key ANCOVA assumption.

Effect of Core Stabilization on Balance Performance

Descriptive statistics and ANCOVA results are presented in Table 1. The experimental group demonstrated a clinically and statistically meaningful improvement in Stork Balance Test performance across the intervention period, with pre-test scores of $M = 12.95$ s ($SD = 8.37$) rising to $M = 17.85$ s ($SD = 8.29$) at mid-test and $M = 23.73$ s at post-test, representing a mean net improvement of +10.78 seconds. In contrast, the control group exhibited negligible change across all measurement points (pre-test: $M = 13.05$ s, $SD = 8.23$; mid-test: $M = 13.16$ s, $SD = 8.06$; post-test: $M = 13.06$ s).

ANCOVA, with pre-test scores as the covariate, revealed a statistically significant main effect of Group on adjusted post-test balance scores ($F(1, 41) = 143$, $p < .001$, $\eta^2 = 0.292$), indicating a large treatment effect. The adjusted post-test mean for the experimental group ($M = 23.78$ s, $SE = 0.638$) was substantially greater than for the control group ($M = 13.01$ s, $SE = 0.638$). The pre-test covariate was also a significant predictor of post-test performance ($F(1, 41) = 304$, $p < .001$, $\eta^2 = 0.623$), confirming the appropriateness of covariate adjustment. The overall model explained a significant proportion of variance in post-test scores ($F(2, 41) = 222$, $p < .001$).

Table 1. Descriptive Statistics and ANCOVA Results for Stork Balance Test Scores (seconds)

Group	n	Pre- test (SD)	Mid- test (SD)	Post- test (SD)	Adjusted Post-test (SE)	Overa ll F	Group F	p-value
Experiment al	22	12.95 (8.37)	17.85 (8.29)	23.73	23.78 (0.638)	222	143	< .001
Control	22	13.05 (8.23)	13.16 (8.06)	13.06	13.01 (0.638)	—	—	—

Note. M = mean; SD = standard deviation; SE = standard error. Stork Balance Test scores are reported in seconds; higher scores denote superior balance performance. ANCOVA covariate = pre-test score. $\eta^2(\text{Group}) = 0.292$ (large effect); $\eta^2(\text{Pre-test covariate}) = 0.623$.

DISCUSSION

This main finding of this study was that a 12-week core stabilization exercise programme resulted in a significantly larger increase in static balance performance in children with intellectual disabilities ($F = 143$, $p = < .001$, $\eta^2 = 0.292$) with the experimental group gaining a mean of +10.78 seconds on the SBP test compared to the control group that had a minimal change in performance. This discovery validates the study hypothesis and provides experimentation evidence to the literature, which has been primarily based on reviews and non-experimental designs.

Mechanistic Interpretation

The changes observed might be due to a number of physiological mechanisms. Core stabilization exercises focus on the deep stabilizing muscles of the lumbopelvic region: the transversus abdominis, multifidus and pelvic floor muscles (Panjabi, 1992). Increasing the strength of these muscles creates lumbopelvic stability allowing for more stable base of proximal limb movements during distal limb movements. It is believed that this enhanced proximal stability leads to less postural sway and resistance to balance perturbations, both of which are important factors in the Stork Balance Test. Also, the repeated performance of the core exercises can improve the proprioceptive feedback mechanisms and neuromuscular coordination often affected in children with ID (McGill, 2010). The cumulative neuromotor adaptation probably contributed to the progressive nature of the 12-week programme, which included strength gains but more than the initial gains were observed.

Contextualisation Within the Literature



The results corroborate those of Zhou et al (2024) in their systematic review and meta-analysis which revealed that core stability exercises were effective in improving dynamic balance in children and adolescents with ID and highlighted the scarcity of high-quality primary experimental evidence. This is addressed directly in the present randomised controlled study. In addition, Janbozorgi et al. (2024) found that balance significantly improved after structured physical activity in children with ID in the Stork Balance Test, similar to the current results. The results of this study in adolescents with ID (mean age 16.2 years) support previous data from Shen et al. (2022) showing that adaptive physical activity had a positive effect on motor function in adolescents with ID. Here, the magnitude of the improvement ($+10.78$ s, $\eta^2 = 0.292$) is noteworthy and may be due to the relatively larger balance deficits at baseline that were found with kids with ID, leading to larger gains from the training than that typically seen with non-disabled children.

Assumption Violations and Interpretive Caveats

Violations of homogeneity of variance and normality assumptions are suggested by a significant Levene's test ($F = 9.98$, $p = .003$) and a significant Shapiro–Wilk test ($W = 0.759$, $p < .001$). The results are generally considered to be robust to moderate violations of ANCOVA, especially if the group sizes are equal; however, these violations indicate results need to be interpreted with proper caution. It would be worthwhile to explore non-parametric alternatives and/or robust statistical methods, especially in small samples, in future studies.

Practical Implications

Immediate practical implications for adapted physical education teachers, physiotherapists, and special educators with children with ID. The activities in this programme are safe, accessible and do not need a lot of equipment, making them suitable for implementation in the school and community. Structured core stabilization training weekly may provide benefits for static balance, postural control, motor function and participation in physical activity for this population.

Limitations and Future Directions

There are a few things to consider when interpreting the results of the present study. First, the sample consisted completely of males, thereby reducing generalisability to females with ID. Second, disability severity (mild, moderate, severe) was not analysed as a sub-group variable; it may be possible that there are differential responses by disability severity. Third, objective measures of core muscle strength and endurance were not included, meaning that the increase in core strength could not be directly



demonstrated to explain the balance improvements. Fourth, a lack of follow up assessment after 12 weeks makes it impossible to draw any conclusions about the long-term maintenance of training-induced gains. Fifth, caution should be exercised in interpreting the parametric ANCOVA findings because of the violations of statistical assumptions.

Future studies should overcome these limitations by having female participants, using sub-group analyses by disability severity, by using objective core strength assessments (e.g. McGill trunk endurance tests), assessing dose-response relationships by varying training intensity and duration, using follow-up evaluations to determine variability of retention, and using robust or non-parametric statistical methods if assumptions are violated.

CONCLUSION

A 12-week core stabilization exercise programme significantly improved static balance performance in male children with intellectual disabilities, as evidenced by a large between-group effect following ANCOVA ($\eta^2 = 0.292$). The control group showed no meaningful change over the same period. These findings support the integration of structured core stability training into adapted physical education and rehabilitation programmes for children with intellectual disabilities. Larger randomised trials with diverse samples, objective physiological measures, and long-term follow-up are needed to substantiate and extend these findings.

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INSECT DIVERSITY ASSOCIATED WITH NATIVE AND INVASIVE PLANT COMMUNITIES ACROSS SEMI-ARID HABITATS IN DEOLA TALUKA OF NASHIK DISTRICT, (M.S), INDIA

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ABSTRACT

Native vegetation plays an important role in sustaining insect diversity in semi-arid agricultural landscapes, whereas invasive plant species often reduce habitat quality and ecosystem functioning. This one-year observational study (July 2022–June 2023) assessed insect diversity associated with native and invasive plant communities across six representative habitats in Deola Taluka, Nashik District, Maharashtra. Field observations were conducted bi-monthly using sweep netting and visual surveys within 10 m × 10 m quadrats. Native plant communities supported 1.8–2.2 times higher insect abundance compared to invasive plant stands. The Shannon Diversity Index was consistently higher for native plants ($H' = 2.84 \pm 0.11$) than for invasive plants ($H' = 1.67 \pm 0.12$). Functional guild analysis showed that pollinators and predators were proportionally more abundant on native vegetation, whereas invasive plant patches were dominated by herbivorous insects.

Insect diversity showed a strong positive correlation with native plant cover and a significant negative relationship with invasive plant dominance. Seasonal patterns indicated peak insect abundance during the post-monsoon period, corresponding with increased vegetation growth and resource availability. The results highlight the ecological importance of conserving native vegetation patches within agricultural landscapes of Deola Taluka to maintain insect biodiversity and associated ecosystem services.

KEYWORDS

Insect diversity, native flora, invasive plants, semi-arid agriculture, Deola Taluka, Nashik District

INTRODUCTION

Insects are vital components of terrestrial ecosystems, contributing to pollination, biological pest control, nutrient cycling, and food-web stability. Global studies have documented substantial declines in insect populations due to habitat loss, land-use change, and biological invasions (Hallmann



et al., 2017). In India, semi-arid regions are particularly vulnerable to biodiversity loss because of agricultural expansion and widespread invasion by alien plant species (Sekar, 2012).

Maharashtra has experienced extensive spread of invasive plants such as *Prosopis juliflora*, *Parthenium hysterophorus*, and *Lantana camara*, especially in rain-fed agricultural landscapes and degraded lands (Patil & Gaikwad, 2020; Gaikwad et al., 2023). These species often replace native vegetation along agricultural margins, grazing lands, and village peripheries, altering habitat structure and resource availability for insects.

Deola Taluka (550–650 m elevation), located in eastern Nashik District, represents a typical semi-arid agro-ecosystem dominated by agriculture, scrub vegetation, and seasonal watercourses connected to the Girna River system. Although floristic studies exist for Nashik District (Salunkhe & Yadav, 2016; Puneekar & Lakshminarasimhan, 2011), quantitative assessments of insect diversity responses to native and invasive vegetation in Deola Taluka remain limited.

We hypothesized that native plant communities would support higher insect diversity and a different functional guild composition compared to invasive plant stands.

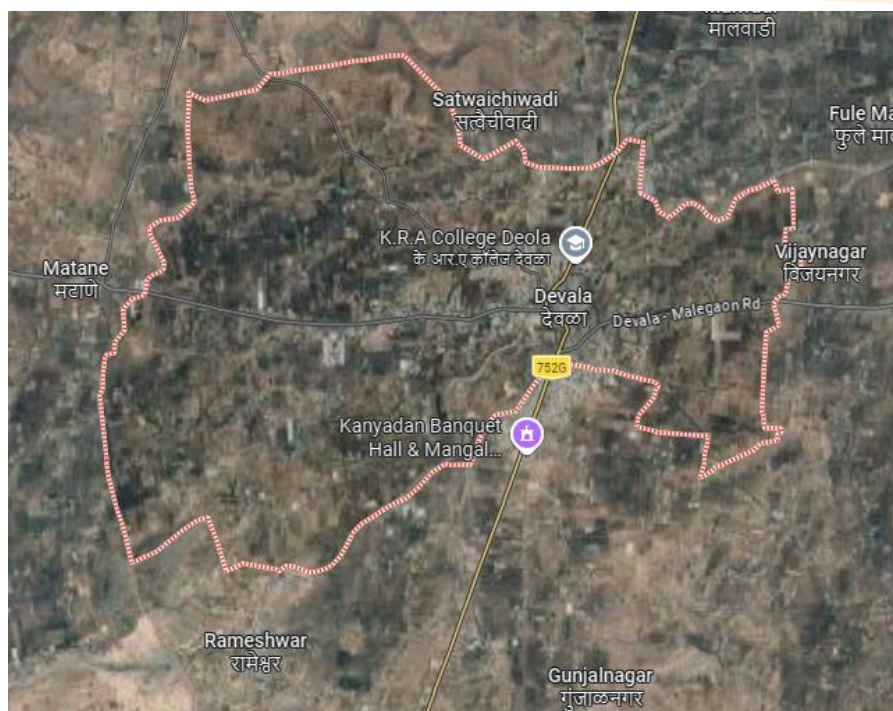
MATERIALS AND METHODS

STUDY AREA

The study was conducted in Deola Taluka, Nashik District, Maharashtra, India (20°24'–20°27' N; 73°59'–74°03' E). The region has a semi-arid climate with annual rainfall of 550–650 mm. Temperatures range from approximately 15 °C in winter to 42 °C in summer. Soils are medium black to shallow brown with pH 7.2–8.1 and organic carbon content of 0.4–0.7%. Major crops include onion, grapes, sorghum, and pearl millet.

Study Sites

Six sites representing agricultural margins, fallow lands, riparian strips, degraded pastures, scrub forest, and crop field borders were selected within Deola Taluka.



Insect Sampling

Sampling was conducted bi-monthly from July 2022 to June 2023 during peak insect activity hours (07:00–10:00 AM). At each site, five 10 m × 10 m quadrats were established. Five quadrats per site were selected based on preliminary sampling to achieve representative habitat coverage. Each quadrat was sampled using 20 sweep-net sweeps and a 15-minute visual search. Across six sites, twelve sampling events, and five quadrats per site, total sampling effort consisted of 360 quadrat observations. Insects were identified to family or genus level using Boruah et al. (2019); difficult specimens were assigned to morphospecies.

Data Analysis

Data were analysed using SPSS v26.0. Paired t-tests compared insect abundance between native and invasive plants across sites. Pearson's correlation coefficient assessed relationships between vegetation cover and insect diversity. Chi-square tests examined differences in functional guild proportions. Seasonal variation was analysed using one-way ANOVA. Statistical significance was set at $p < 0.05$.

RESULTS

Site Characteristics and Habitat Descriptions

Table 1. Location and habitat characteristics of study sites in Deola Taluka

Site	Location	GPS Coordinates	Elevation (m a.s.l.)	Land Use	Dominant Native Plants	Dominant Invasive Plants
S1	Deola Market	20°25'12" N, 74°01'12" E	580	Agricultural margin	<i>Ziziphus mauritiana</i> , <i>Azadirachta indica</i>	<i>Parthenium hysterophorus</i>
S2	Saturna village	20°26'10" N, 74°02'05" E	590	Fallow land	<i>Acacia leucophloea</i> , <i>Calotropis gigantea</i>	<i>Prosopis juliflora</i>
S3	Girna river bank	20°27'15" N, 74°03'20" E	570	Riparian strip	<i>Prosopis cineraria</i> , <i>Capparis decidua</i>	<i>Prosopis juliflora</i> , <i>Lantana camara</i>
S4	Ambad link road	20°24'30" N, 73°59'40" E	600	Degraded pasture	<i>Balanites aegyptiaca</i> , <i>Dodonaea viscosa</i>	<i>Prosopis juliflora</i> , <i>Parthenium hysterophorus</i>
S5	Deola hill slope	20°25'45" N, 74°00'30" E	610	Scrub forest	<i>Acacia leucophloea</i> , <i>Ziziphus oenopia</i>	<i>Lantana camara</i>
S6	Crop field border	20°24'05" N, 74°01'50" E	575	Agricultural fields	Native herbs and grasses	<i>Parthenium hysterophorus</i>

The six study sites represented diverse habitat types within Deola Taluka, including agricultural margins, fallow lands, riparian strips, degraded pastures, scrub forest, and crop field borders (Table 1). Variation in elevation, land use, and vegetation composition provided a suitable gradient for assessing insect responses to native and invasive plants.

Insect Abundance on Native and Invasive Plants

Table 2. Insect abundance on native and invasive plants (Values represent mean $\pm$ SD of bi-monthly sampling across 12 months.)

Site	Native Plants	Invasive Plants	Ratio
S1	162 $\pm$ 18	78 $\pm$ 12	2.08
S2	128 $\pm$ 15	71 $\pm$ 10	1.80
S3	115 $\pm$ 20	52 $\pm$ 8	2.21
S4	95 $\pm$ 12	48 $\pm$ 9	1.98
S5	142 $\pm$ 16	85 $\pm$ 11	1.67
S6	178 $\pm$ 22	91 $\pm$ 14	1.96

Native plants supported significantly higher insect abundance (paired t-test: $t = 8.92$, $df = 5$, $p < 0.001$).

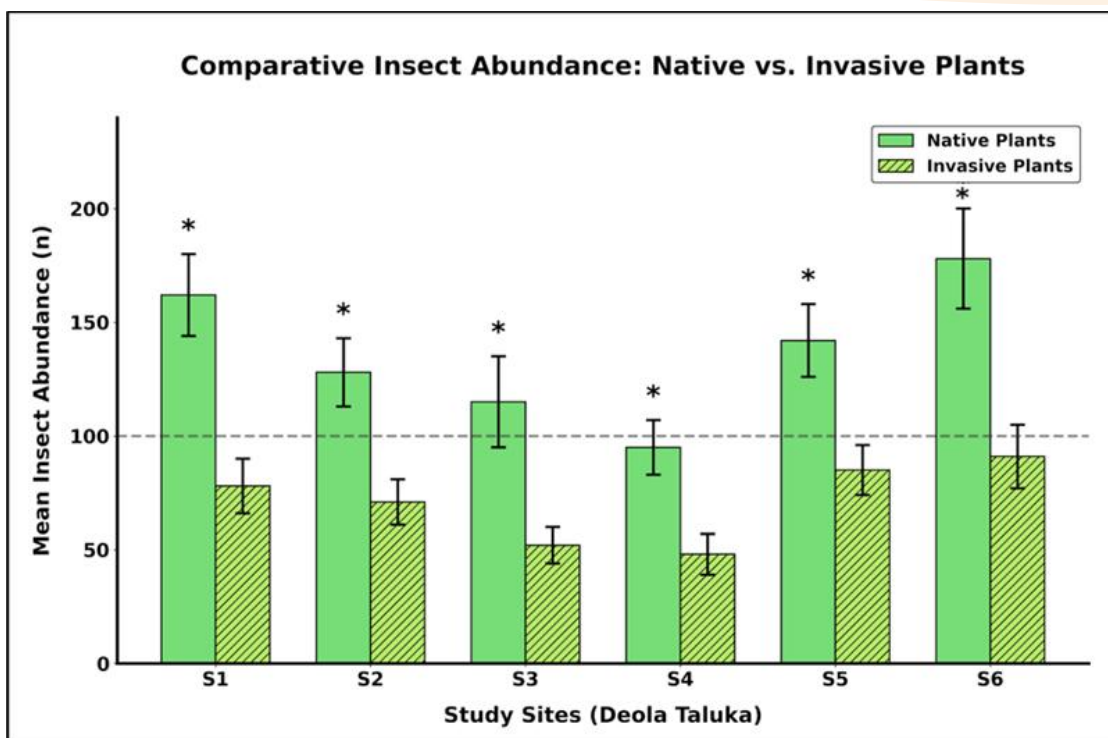


Figure 1. Comparative insect abundance on native and invasive plant communities across six study sites in Deola Taluka. Native plants supported significantly higher insect abundance than invasive plants at all sites (mean $\pm$ SD).

Native plant communities supported significantly higher insect abundance than invasive plants across all six study sites (Table 2). Mean insect abundance on native vegetation was approximately 1.67–2.21 times higher than that recorded on invasive plant stands, and this difference was statistically significant (paired t-test: $t = 8.92$, $df = 5$, $p < 0.001$). The consistent dominance of native plants in supporting higher insect abundance across sites is clearly illustrated in Figure 1.

Functional Guild Composition

Table 3. Functional guild composition of insects (%)

Functional Guild	Native Plants	Invasive Plants
Pollinators	38	17
Herbivores	26	44
Predators	22	25
Detritivores	14	14

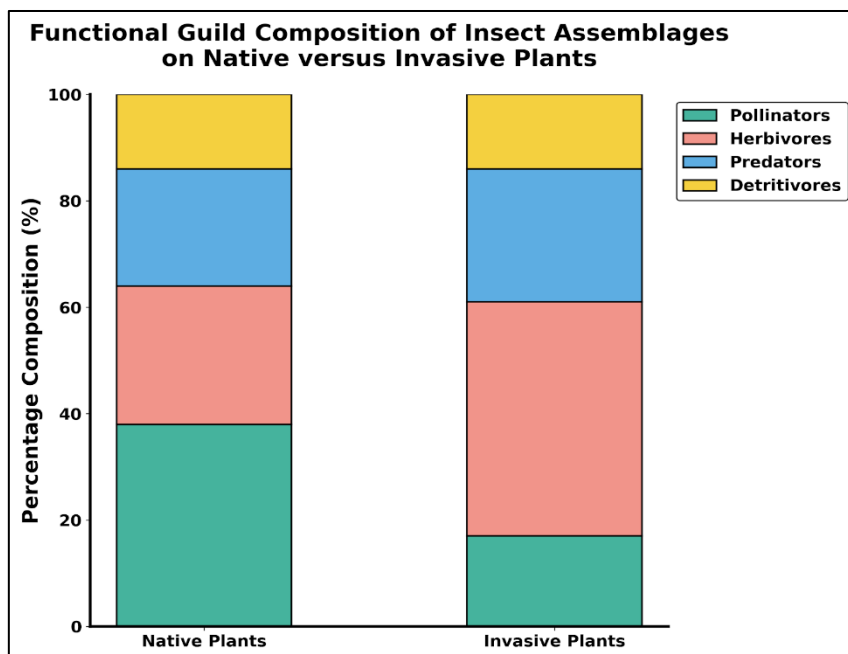


Figure 2. Functional guild composition (%) of insect assemblages associated with native and invasive plant communities in Deola Taluka. Native plants supported higher proportions of pollinators, whereas invasive plants were dominated by herbivorous insects.

Clear differences were observed in the functional guild composition of insects associated with native and invasive plant communities (Table 3). Native plants supported a higher proportion of pollinators (38%) compared to invasive plants (17%), whereas invasive plant stands were dominated by herbivorous insects (44% versus 26% on native plants). Predators and detritivores contributed moderately to both vegetation types. These differences in guild structure are visually summarized in Figure 2.

Table 4. Seasonal variation in insect abundance (mean $\pm$ SD)

Season	Native Plants	Invasive Plants
Monsoon (Jul-Sep)	132 $\pm$ 16	68 $\pm$ 9
Post-monsoon (Oct-Dec)	156 $\pm$ 21	79 $\pm$ 12
Winter (Jan-Feb)	121 $\pm$ 18	65 $\pm$ 9
Summer (Mar-Jun)	98 $\pm$ 14	54 $\pm$ 8

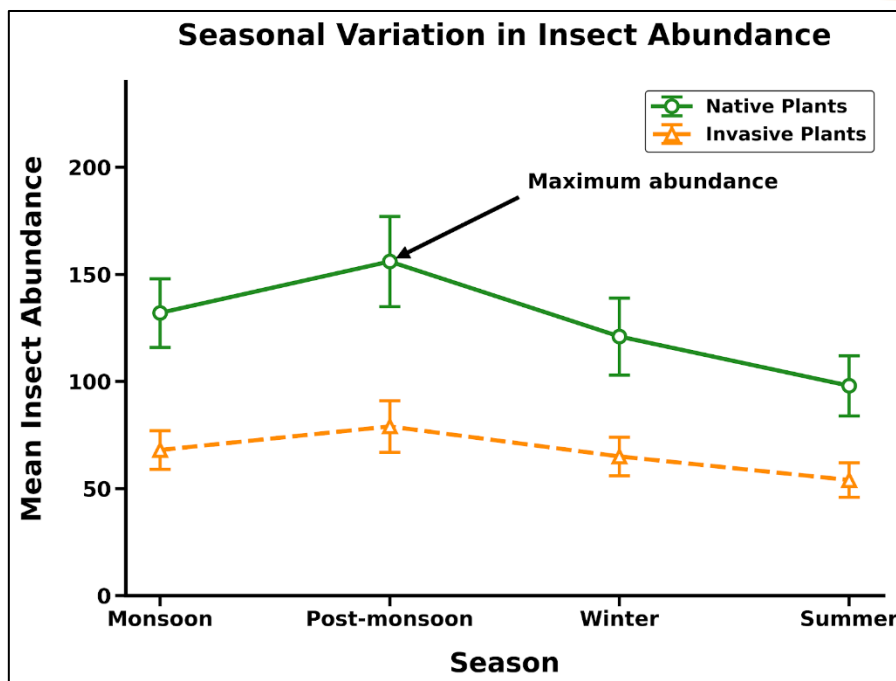


Figure 4. Seasonal variation in mean insect abundance ($\pm$ SD) associated with native and invasive plant communities in Deola Taluka.

Seasonal variation in insect abundance was observed for both native and invasive plant communities (Table 4). Insect abundance peaked during the post-monsoon season for both vegetation types, followed by a gradual decline during winter and summer months. Native plants consistently supported higher insect abundance than invasive plants across all seasons. This seasonal pattern is clearly illustrated in Figure 4.

Diversity Metrics

Table 5. Shannon Diversity Index (H') and species richness

Site	Native H'	Invasive H'	Native Richness	Invasive Richness
S1	2.85	1.72	32	15
S2	2.78	1.68	30	14
S3	2.91	1.58	28	12
S4	2.65	1.49	26	11
S5	2.88	1.76	31	16
S6	2.95	1.81	34	17
Mean $\pm$ SD	2.84 $\pm$ 0.11	1.67 $\pm$ 0.12	30.2 $\pm$ 2.8	14.2 $\pm$ 2.1

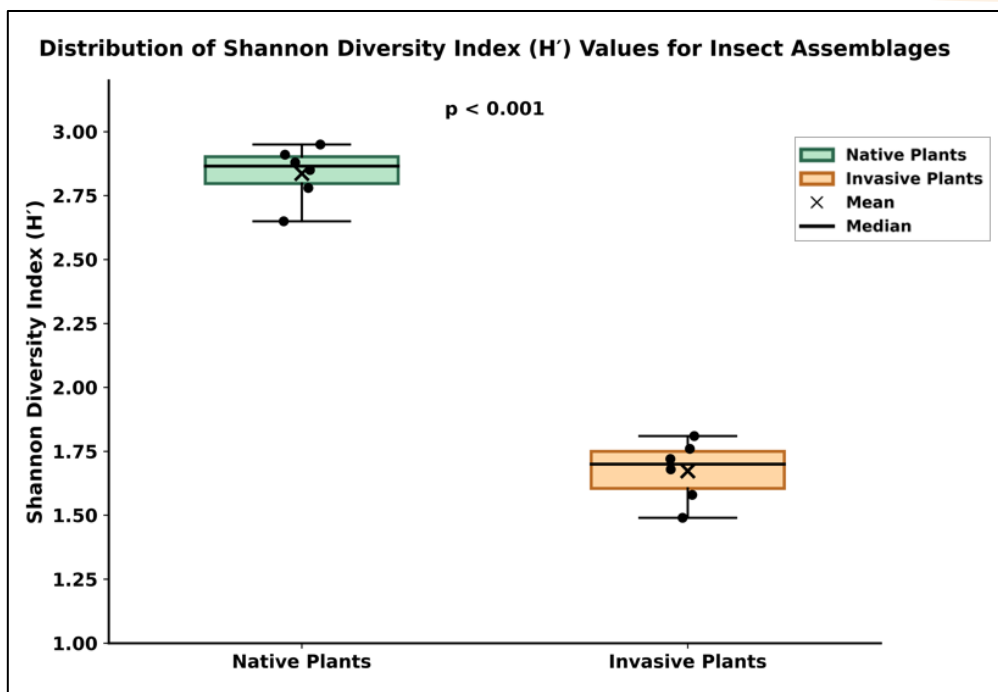


Figure 3. Distribution of Shannon Diversity Index (H') values for insect assemblages associated with native and invasive plant communities in Deola Taluka. Native plant assemblages show higher median diversity and lower variability compared to invasive plant stands.

Shannon Diversity Index (H') values were consistently higher for insect assemblages associated with native plants than invasive plants (Table 5). Native vegetation showed H' values ranging from 2.65 to 2.95 (mean = 2.84 ± 0.11), whereas invasive plant assemblages exhibited lower diversity values ranging from 1.49 to 1.81 (mean = 1.67 ± 0.12). Species richness followed a similar pattern, with native plants supporting a higher number of species compared to invasive plants. The distribution and variability of Shannon diversity values between vegetation types are illustrated in Figure 3.

Correlation Analysis

Table 6. Correlation between vegetation cover and insect diversity

Variable	r-value	p-value	Significance
Native cover vs diversity	+0.86	0.014	Significant
Invasive cover vs diversity	-0.79	0.032	Significant
Native cover vs pollinators	+0.82	0.023	Significant

Correlation analysis revealed a strong positive relationship between native plant cover and insect diversity (Table 6). In contrast, invasive plant cover showed a significant negative correlation with insect diversity. Native plant cover was also positively correlated with pollinator abundance, indicating that sites with higher native vegetation supported greater pollinator representation.

DISCUSSION

The present study demonstrates that native plant communities in Deola Taluka play a crucial role in sustaining higher insect abundance, species richness, and functional diversity compared to invasive plant stands. Across all six study sites, insect abundance was consistently higher on native vegetation, with values ranging from 1.67 to 2.21 times greater than those recorded on invasive plants. This clear and statistically significant pattern indicates that native plants provide more suitable habitat conditions for insect assemblages. Similar observations have been reported from other semi-arid regions of Maharashtra, where native vegetation supports richer and more stable insect communities than invasive-dominated habitats (Patil et al., 2019; Kamble et al., 2020; Kumbhar et al., 2023).

Higher insect diversity associated with native plants can be attributed to greater structural complexity, diverse food resources, and long-standing ecological associations between native plants and insects (Tallamy et al., 2021). Native species such as *Acacia leucophloea*, *Ziziphus* spp., and *Prosopis cineraria* provide nesting sites, shelter, and seasonally available nectar and pollen, supporting both specialist and generalist insects. In contrast, invasive species like *Prosopis juliflora* and *Parthenium hysterophorus* form dense monospecific stands that reduce habitat heterogeneity and limit resource availability, thereby supporting fewer insect taxa. Similar negative effects of invasive plants on insect diversity have been documented in Nashik District and other dry regions of India (Patil & Gaikwad, 2020; Gaikwad et al., 2023).

Functional guild analysis further revealed ecological shifts associated with vegetation type. Native plants supported a higher proportion of pollinators, whereas invasive plant stands were dominated by herbivores. This pattern has important implications for agro-ecosystems in Deola Taluka, where crops such as grapes and onions partly depend on insect pollination (Jadhav et al., 2021; More & Jadhav, 2022). Seasonal patterns showed peak insect abundance during the post-monsoon period, reflecting increased vegetation growth and resource availability. Strong positive correlations between native plant cover and insect diversity, and negative correlations with invasive cover, further support the habitat heterogeneity hypothesis (Kumar et al., 2018; IPBES, 2019).



LIMITATIONS AND FUTURE RESEARCH

This study was limited to one year and focused on above-ground insects. Identification was primarily morphological. Future studies should include multi-year monitoring, molecular identification techniques, and soil arthropod assessments.

ETHICS STATEMENT

No ethical approval was required for this observational study of insects conducted in non-protected areas.

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IN VITRO EVALUATION OF FRESHWATER ALGAL EXTRACTS AS NATURAL ANTIFUNGAL AGENTS AGAINST SEED-BORNE FUNGAL PATHOGENS OF PHASEOLUS VULGARIS L.

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ABSTRACT

Seed-borne fungal pathogens are a major cause of yield loss in kidney bean (*Phaseolus vulgaris* L.). Among them, *Fusarium oxysporum*, *Fusarium solani*, and *Macrophomina phaseolina* are responsible for serious diseases such as wilt, root rot, damping-off, and charcoal rot, which reduce both crop productivity and seed quality. Although chemical fungicides are widely used to control these diseases, their repeated and excessive application has resulted in environmental contamination, the development of fungicide-resistant pathogens, and negative effects on beneficial soil microorganisms. Therefore, there is an increasing need to identify safe and sustainable alternatives for disease management. Freshwater algae are recognized as a valuable source of natural bioactive compounds, including phenolic compounds, flavonoids, terpenoids, alkaloids, and fatty acids, many of which exhibit antimicrobial activity. In the present study, the antifungal activity of methanolic freshwater algal extracts was evaluated against *Fusarium oxysporum*, *Fusarium solani*, and *Macrophomina phaseolina* under laboratory conditions. The poisoned food technique was employed by incorporating different concentrations of algal extracts into Potato Dextrose Agar (PDA) medium. Antifungal efficacy was determined by measuring the radial growth of fungal colonies and calculating the percentage inhibition in comparison with the untreated control.

The results demonstrated that the algal extracts significantly inhibited the mycelial growth of all three fungal pathogens. The inhibitory effect increased with increasing extract concentration, indicating a concentration-dependent response. Fungal colonies grown on algal extract-amended medium showed reduced colony diameter, limited sporulation, and abnormal hyphal morphology compared with the untreated control. These observations confirm the strong antifungal potential of freshwater algal extracts against important seed-borne pathogens of kidney bean. The findings of this study suggest that



freshwater algal extracts can serve as effective and environmentally friendly bio-fungicidal agents for the management of seed-borne fungal diseases. Their use may reduce dependence on synthetic fungicides and contribute to the development of sustainable and eco-friendly crop protection strategies in *Phaseolus vulgaris* cultivation.

KEYWORDS

Freshwater algae; *Phaseolus vulgaris* L.; antifungal activity; seed-borne fungi; poisoned food technique; *Fusarium oxysporum*; *Fusarium solani*; *Macrophomina phaseolina*; bio-fungicide; sustainable disease management.

INTRODUCTION

Kidney bean (*Phaseolus vulgaris* L.) is one of the most widely cultivated grain legumes in the world because of its high nutritional value and economic importance. The seeds are rich in proteins, carbohydrates, dietary fibre, vitamins, and essential minerals, making kidney bean an important component of a balanced human diet, particularly in developing countries. In India, the crop is cultivated for both green pods and dry seeds and plays a significant role in improving food and nutritional security. In addition to its nutritional value, kidney bean contributes to soil fertility through biological nitrogen fixation, thereby supporting sustainable agricultural production (Broughton et al., 2003; Beebe, 2012).

Despite its importance, kidney bean production is greatly affected by several fungal diseases, especially those caused by seed-borne and soil-borne pathogens. Among these, *Fusarium oxysporum*, *Fusarium solani*, and *Macrophomina phaseolina* are considered the most destructive pathogens. *Fusarium oxysporum* causes vascular wilt, which results in yellowing of leaves, wilting, and eventual plant death due to blockage of water-conducting tissues. *Fusarium solani* is responsible for root rot and seed decay, leading to poor seed germination, weak seedlings, and reduced plant growth. *Macrophomina phaseolina*, the causal agent of charcoal rot, infects a wide range of agricultural crops and survives in soil for extended periods through resistant structures known as sclerotia, making disease management difficult under field conditions (Agrios, 2005; Leslie and Summerell, 2006; Gupta et al., 2012).

Management of these fungal diseases mainly depends on synthetic fungicides. Although these chemicals provide rapid and effective disease control, their repeated and excessive use has created several environmental and agricultural problems. Continuous application of fungicides can



contaminate soil and water resources, leave harmful chemical residues in agricultural products, reduce populations of beneficial soil microorganisms, and promote the development of fungicide-resistant pathogen strains. These limitations have encouraged researchers to explore safer and environmentally sustainable alternatives for plant disease management (Brent and Hollomon, 2007; Javed et al., 2021; FRAC, 2024).

Natural products obtained from biological resources have gained considerable attention as eco-friendly alternatives to synthetic pesticides. Among these, freshwater algae are recognized as a valuable source of biologically active compounds with diverse agricultural applications. Freshwater algal species produce a wide range of secondary metabolites, including phenolic compounds, flavonoids, alkaloids, terpenoids, fatty acids, pigments, sterols, and sulphated polysaccharides. Many of these compounds possess antimicrobial, antioxidant, and plant growth-promoting properties, making algae an attractive resource for sustainable crop protection (Khan et al., 2009; El-Sheekh et al., 2021; Chiaiese et al., 2023).

The antifungal activity of algal extracts has been attributed to their ability to interfere with several physiological processes of fungal pathogens. Bioactive metabolites present in algae can damage fungal cell membranes, alter membrane permeability, inhibit enzyme activity, suppress cell wall synthesis, reduce spore germination, and restrict mycelial growth. As a result, algal extracts can effectively reduce fungal infection without causing the environmental hazards associated with synthetic fungicides. Recent studies have demonstrated that freshwater and marine algal extracts inhibit the growth of several economically important phytopathogenic fungi under laboratory and greenhouse conditions (Begum et al., 2016; El-Mougy and Abdel-Kader, 2013; El-Sheekh et al., 2021; Chiaiese et al., 2023).

Evaluation of natural antifungal compounds is commonly carried out using the poisoned food technique described by Nene and Thapliyal (1979). This method involves incorporating the test extract directly into Potato Dextrose Agar (PDA) medium before fungal inoculation. The continuous exposure of fungal cultures to the bioactive compounds allows accurate assessment of antifungal activity by measuring radial mycelial growth and calculating the percentage inhibition relative to the untreated control. Because of its simplicity, reproducibility, and reliability, this technique is widely used for screening plant and algal extracts against phytopathogenic fungi.

Considering the increasing demand for environmentally safe disease management practices and the rich antimicrobial potential of freshwater algae, the present study was undertaken to evaluate the

antifungal activity of methanolic freshwater algal extracts against *Fusarium oxysporum*, *Fusarium solani*, and *Macrophomina phaseolina*, the major seed-borne fungal pathogens associated with kidney bean (*Phaseolus vulgaris* L.). The findings of this investigation may contribute to the development of algae-based bio-fungicides as sustainable alternatives to conventional chemical fungicides for crop protection.

MATERIALS AND METHODS

Collection of Freshwater Algae

Freshwater algae were collected from different ponds, reservoirs, and other freshwater habitats located in the study area. Healthy algal thalli were manually collected and transferred to the laboratory in clean, sterile plastic containers. The collected samples were washed thoroughly with tap water to remove mud, sand, and other debris, followed by repeated washing with distilled water to eliminate attached microorganisms and unwanted impurities. The cleaned algal biomass was shade-dried at room temperature (25–30°C) for 10–12 days until a constant dry weight was obtained. The dried material was then ground into a fine powder using an electric grinder and stored in airtight containers at room temperature until extraction. (Rajasulochana et al., 2009; El-Sheekh et al., 2021).

Preparation of Algal Extract-

1. Freshwater algal samples were shade-dried and ground into a fine powder.
2. Approximately 25 g of the dried algal powder was weighed.
3. The powder was extracted with 100 mL of methanol using a Soxhlet extraction apparatus.
4. The extraction was carried out continuously for 24 hours to obtain the maximum number of bioactive compounds.
5. After extraction, the methanolic extract was filtered through Whatman No. 1 filter paper.
6. The filtered extract was concentrated under reduced pressure using a rotary vacuum evaporator to remove the methanol and obtain the crude algal extract.
7. The concentrated crude extract was transferred into sterile glass flasks.
8. Methanol was selected as the extraction solvent because it efficiently extracts a wide range of bioactive compounds.
9. These bioactive compounds are reported to possess antifungal and antimicrobial properties, making methanolic algal extracts suitable for evaluating their activity against plant pathogenic fungi (Harborne, 1998; El-Sheekh et al., 2021; Chiaiese et al., 2023).

Test Fungal Pathogens

The antifungal activity of methanolic freshwater algal extracts was evaluated against three major seed-borne fungal pathogens of kidney bean (*Phaseolus vulgaris* L.), namely *Fusarium oxysporum*, *Fusarium solani*, and *Macrophomina phaseolina*. Pure cultures of the fungal pathogens were maintained on Potato Dextrose Agar (PDA) medium under laboratory conditions. The cultures were regularly subcultured to maintain their viability, purity, and active growth throughout the experimental period. Actively growing seven-day-old fungal cultures were used as the inoculum for all antifungal assays to ensure uniform and reliable experimental results (Dhingra and Sinclair, 1995).

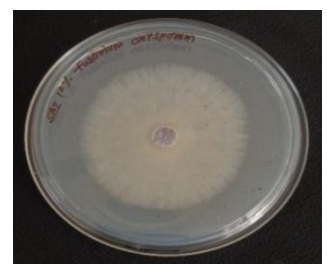
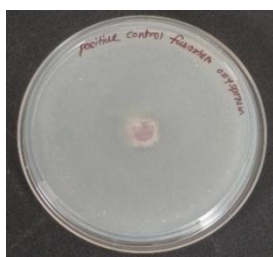
Evaluation of Antifungal Activity by the Poisoned Food Technique

The antifungal activity of the methanolic freshwater algal extracts was evaluated using the poisoned food technique described by Nene and Thapliyal (1979). Potato Dextrose Agar (PDA) medium was prepared following standard microbiological procedures and sterilized in an autoclave at 121°C and 15 psi pressure for 20 min. After sterilization, the medium was cooled to approximately 45°C before the addition of the algal extracts.

Different concentrations of the methanolic algal extract (1%, 5%, 10%, 15%, 20%, and 25%) were separately mixed with the PDA medium under aseptic conditions. PDA medium without algal extract served as the untreated control. The amended medium was poured into sterile Petri plates and allowed to solidify at room temperature. Each treatment was performed in triplicate to ensure the reliability and reproducibility of the results. The inoculated plates were incubated at $27 \pm 2^\circ\text{C}$ for 7 days under laboratory conditions.

After the incubation period, the radial growth of each fungal colony was measured in centimetres, and the antifungal activity of the algal extracts was determined by comparing the colony diameter of the treated plates with that of the untreated control.

Each treatment was replicated three times, and the average values were calculated.



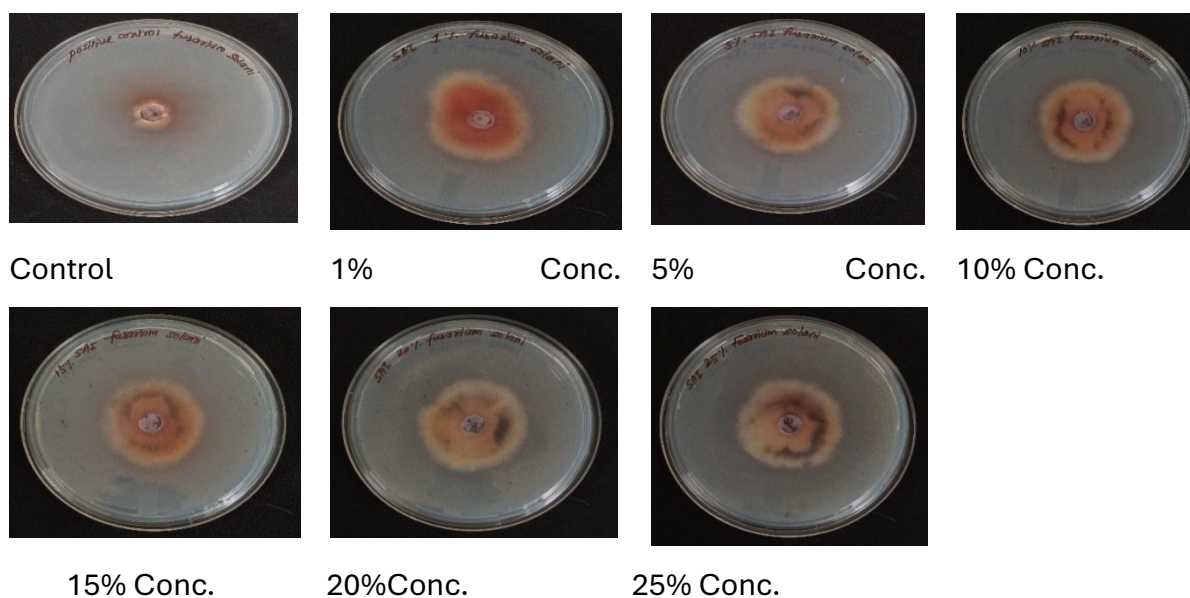
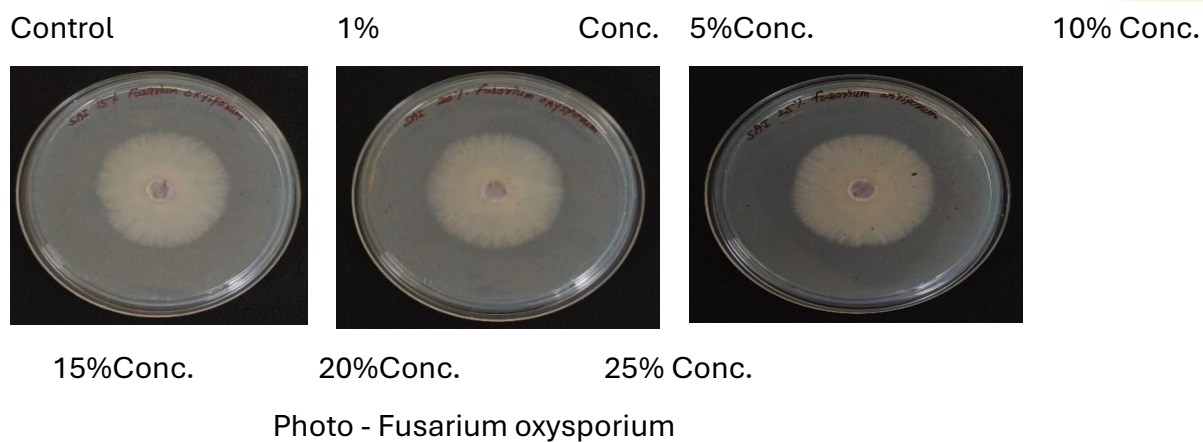
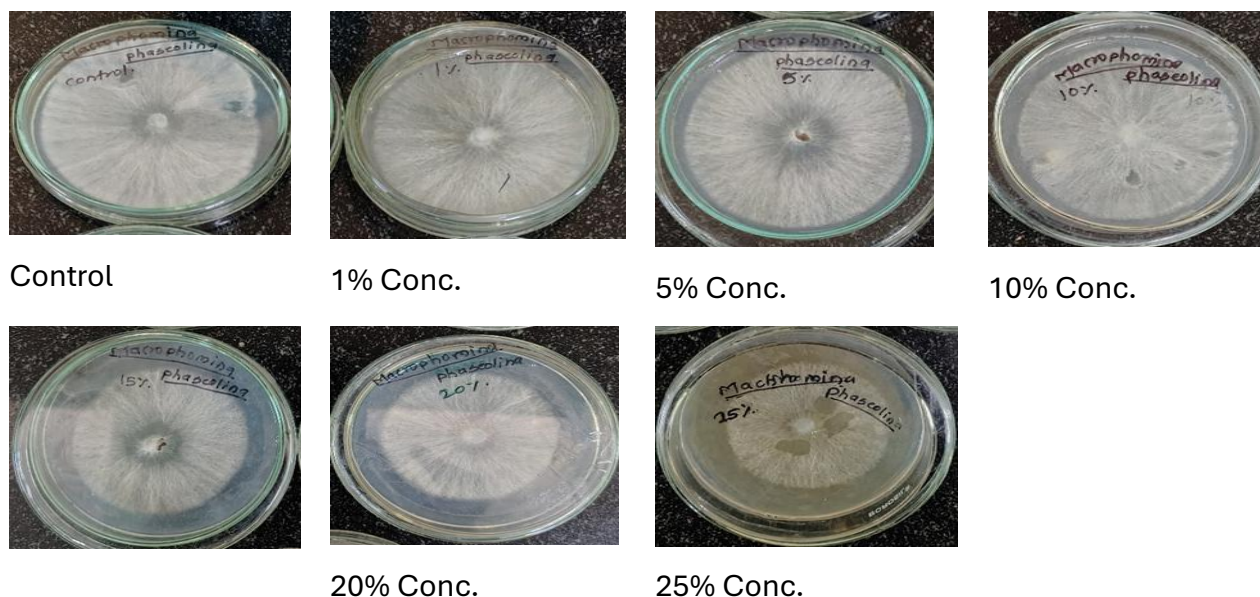


Fig. *Fusarium solani*



15% Conc.

Photo-Macrophomina phaseolina

Table. 01 Effect of treatment concentration on mycelial growth of different phytopathogenic fungi

Treatment concentration	Fusarium solani	Fusarium oxysporum	Macrophomina phaseolina
Control	5.17 ± 0.06	5.73 ± 0.06	6.93 ± 0.12
1%	3.97 ± 0.06 (23.23)	5.33 ± 0.06 (6.98)	6.70 ± 0.00 (3.37)
5%	3.77 ± 0.06 (27.10)	5.23 ± 0.06 (8.72)	6.17 ± 0.12 (11.06)
10%	3.67 ± 0.06 (29.03)	5.13 ± 0.06 (10.47)	5.80 ± 0.17 (16.35)
15%	3.57 ± 0.06 (30.97)	4.93 ± 0.06 (13.95)	5.40 ± 0.00 (22.12)
20%	3.47 ± 0.06 (32.90)	4.53 ± 0.06 (20.93)	5.50 ± 0.00 (20.67)
25%	3.17 ± 0.06 (38.71)	4.33 ± 0.06 (24.42)	5.27 ± 0.12 (24.04)
ANOVA, F (6,14)	371.57*	207.00*	128.44*
p-value	<0.001*	<0.001*	<0.001*

Table 02 One-way ANOVA of antifungal activity by food poison method

Fungus	Source of variation	SS	df	MS	F-value	p-value	Significance
Fusarium solani	Between treatments	7.4314	6	1.2386	371.571	1.31 × 10 ⁻¹⁴	***
	Within treatments (Error)	0.0467	14	0.0033			
	Total	7.4781	20				

Fusarium oxysporum	Between treatments	4.1400	6	0.6900	207.000	7.55 × 10 ⁻¹³	***
	Within treatments (Error)	0.0467	14	0.0033			
	Total	4.1867	20				
Macrophomina phaseolina	Between treatments	7.7067	6	1.2844	128.444	2.01 × 10 ⁻¹¹	***
	Within treatments (Error)	0.1400	14	0.0100			
	Total	7.8467	20				

One-way ANOVA revealed a highly significant effect of treatment concentration on mycelial growth of all three tested fungi. The effect was strongest for *F. solani* ($F_{6,14} = 371.57$, $p < 0.001$), followed by *F. oxysporum* ($F_{6,14} = 207.00$, $p < 0.001$) and *M. phaseolina* ($F_{6,14} = 128.44$, $p < 0.001$).

RESULTS

Antifungal activity against phytopathogenic fungi

The antifungal activity of the treatment was evaluated against *Fusarium solani*, *Fusarium oxysporum*, and *Macrophomina phaseolina* using the poisoned food technique. Mycelial growth was measured in centimetres after incubation, and the percentage inhibition of fungal growth was calculated in comparison with the untreated control. A clear inhibitory effect of the treatment was observed against all three tested fungal pathogens. In general, mycelial growth decreased with increasing treatment concentration. However, the magnitude of inhibition varied among the fungal species. Against *Fusarium solani*, the mean mycelial growth in the control was 5.17 ± 0.06 cm. Treatment with 1%, 5%, 10%, 15%, 20%, and 25% concentrations reduced the mycelial growth to 3.97 ± 0.06 , 3.77 ± 0.06 , 3.67 ± 0.06 , 3.57 ± 0.06 , 3.47 ± 0.06 , and 3.17 ± 0.06 cm, respectively. The corresponding inhibition of mycelial growth was 23.23%, 27.10%, 29.03%, 30.97%, 32.90%, and 38.71%. The maximum inhibition was therefore recorded at 25% concentration. A similar inhibitory response was observed in *Fusarium oxysporum*. The control showed a mean mycelial growth of 5.73 ± 0.06 cm, whereas growth decreased to 5.33 ± 0.06 cm at 1% and progressively to 4.33 ± 0.06 cm at 25%. The percentage inhibition increased from 6.98% at 1% to 24.42% at 25%. Thus, the highest concentration produced the greatest reduction in mycelial growth. In *Macrophomina phaseolina*, the control recorded the highest mean mycelial

growth of 6.93 ± 0.12 cm. The growth decreased to 6.70 ± 0.00 , 6.17 ± 0.12 , 5.80 ± 0.17 , 5.40 ± 0.00 , 5.50 ± 0.00 , and 5.27 ± 0.12 cm at 1%, 5%, 10%, 15%, 20%, and 25%, respectively. The corresponding inhibition values were 3.37%, 11.06%, 16.35%, 22.12%, 20.67%, and 24.04%. The maximum inhibition was observed at 25% concentration (24.04%).

One-way analysis of variance showed that the effect of treatment concentration on mycelial growth was highly significant for all three fungal pathogens. For *F. solani*, the treatment effect was highly significant ($F_{6,14} = 371.57$, $p < 0.001$). Similarly, significant differences were observed for *F. oxysporum* ($F_{6,14} = 207.00$, $p < 0.001$) and *M. phaseolina* ($F_{6,14} = 128.44$, $p < 0.001$). These results indicate that treatment concentration had a significant effect on the growth of all the tested fungi. Among the three pathogens, *F. solani* showed the highest sensitivity to the treatment, with 38.71% inhibition at 25% concentration. The inhibition observed against *F. oxysporum* and *M. phaseolina* at the same concentration was 24.42% and 24.04%, respectively.

DISCUSSION

The present study demonstrated that the treatment possesses antifungal activity against all three tested phytopathogenic fungi. The poisoned food assay showed a general reduction in fungal mycelial growth with increasing treatment concentration. The significant ANOVA results further confirmed that the observed differences in fungal growth among the treatment concentrations were statistically significant. The strongest antifungal activity was observed against *Fusarium solani*. At the highest concentration tested (25%), mycelial growth was reduced from 5.17 cm in the control to 3.17 cm, corresponding to 38.71% inhibition. The comparatively greater inhibition of *F. solani* suggests that this fungus may be more sensitive to the active antifungal constituents present in the treatment. The treatment also inhibited the growth of *F. oxysporum*, although the response was lower than that observed for *F. solani*. At 25% concentration, mycelial growth was reduced by 24.42%. The progressive increase in inhibition from 6.98% at 1% to 24.42% at 25% suggests that increasing the concentration increased the availability of antifungal compounds and consequently restricted fungal growth.

A similar inhibitory pattern was observed for *M. phaseolina*. The maximum inhibition was 24.04% at 25% concentration. Interestingly, the inhibition at 15% (22.12%) was slightly higher than that at 20% (20.67%). This small variation indicates that the response was not completely linear at all concentrations. Such variation may occur because of differences in fungal growth behaviour, biological variability among replicates, or differences in the sensitivity of the pathogen to the active compounds.



The differences in susceptibility among the three fungal pathogens may be related to variations in their cellular structure, growth characteristics, and ability to tolerate or metabolize antifungal compounds. The higher inhibition of *F. solani* compared with *F. oxysporum* and *M. phaseolina* indicates that the antifungal activity is pathogen-dependent.

The highly significant ANOVA values obtained for all three fungi provide strong statistical evidence that the treatment concentrations influenced fungal growth. However, the magnitude of the response differed among the pathogens. Overall, the results indicate that the treatment has potential as a natural antifungal agent, particularly against *F. solani*. The activity observed against *F. oxysporum* and *M. phaseolina* also supports its broader antifungal potential.

The present findings suggest that increasing treatment concentration can improve suppression of fungal mycelial growth. The highest concentration tested (25%) produced the greatest inhibition for all three pathogens. Further studies involving higher concentrations, minimum inhibitory concentration determination, identification of the active antifungal compounds, and in vivo evaluation are required to confirm the practical potential of the treatment for management of these phytopathogenic fungi.

CONCLUSION

The present study demonstrated that the tested treatment exhibited significant antifungal activity against the three phytopathogenic fungi, namely *Fusarium solani*, *Fusarium oxysporum*, and *Macrophomina phaseolina*, as evaluated by the poisoned food technique. A general reduction in mycelial growth was observed with increasing treatment concentration. Among the tested pathogens, *F. solani* showed the highest sensitivity, with maximum inhibition of 38.71% at 25% concentration, followed by *F. oxysporum* (24.42%) and *M. phaseolina* (24.04%). One-way ANOVA confirmed that the effect of treatment concentration on fungal growth was highly significant ($p < 0.001$) for all three pathogens. The observed antifungal activity indicates that the treatment has potential for suppressing important phytopathogenic fungi and may serve as an alternative or supplementary approach to conventional fungicides. However, further investigations are required to identify the active antifungal constituents, determine their mode of action, establish effective concentrations, and validate the antifungal efficacy under greenhouse and field conditions. These studies will help to assess its practical potential as an eco-friendly and sustainable option for fungal disease management.

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